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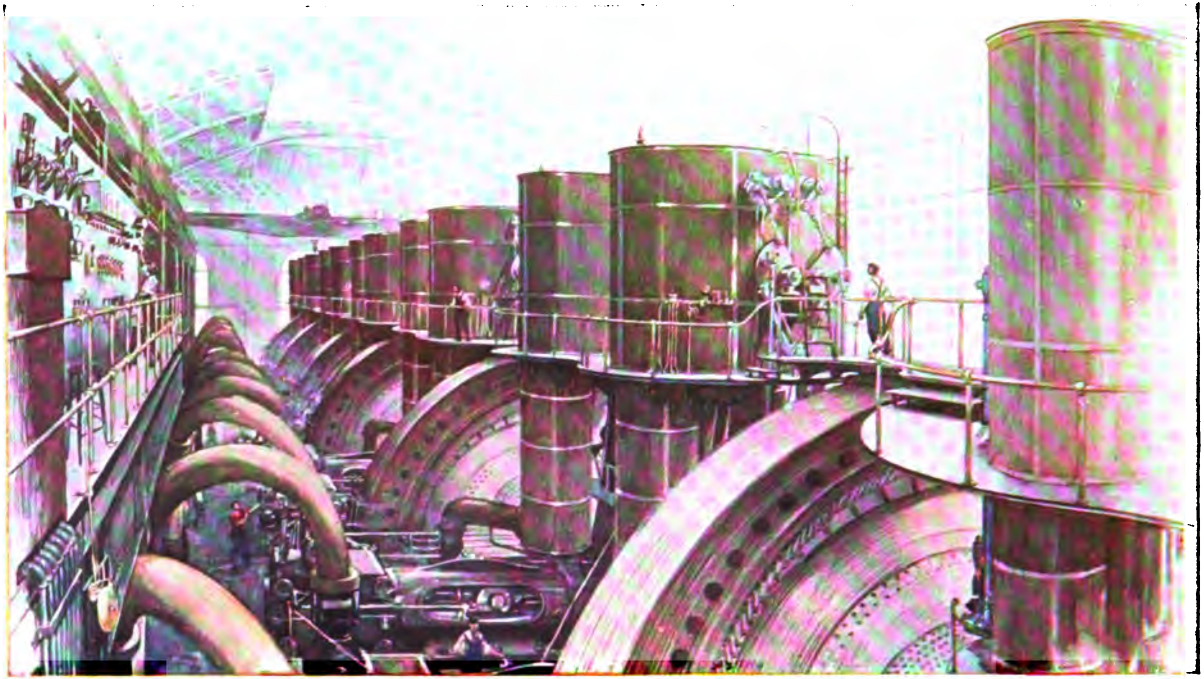

A CENTRAL ELECTRIC GENERATING STATION

Elec.—Vol. II Frontispiece

ELECTRICITY IN EVERY-DAY LIFE

IN THREE VOLUMES

BY

EDWIN J. HOUSTON, Ph.D.

Author of "A Dictionary of Electric Words, Terms and Phrases," "Electro-Technical Series," "Electric Transmission of Intelligence," "Electricity and Magnetism," "Electricity One Hundred Years Ago and To-day," "Recent Types of Dynamo-Electric Machines," "Electricity Made Easy," Etc.

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ELECTRICITY IN EVERY-DAY LIFE

(VOL. II)

SECOND PART

THE ELECTRIC ARTS AND SCIENCES

"*Art and science have their meeting point in method.*"—BULWER

INTRODUCTION

ALTHOUGH the dynamo-electric machine as an electric source might properly be included under the head of the generation of electricity in Volume I, Part I, yet it is more convenient to discuss both it and the electric motor under the electric arts and sciences. This is especially the case, since the construction and operation of the dynamo and motor embrace the highest principles of the electric arts, while their design requires on the part of the electrical engineer a most intimate acquaintance with the sciences of electricity and magnetism.

Why the dynamo and electric motor are included in Part II, Vol. II.

No one would question the propriety of considering the construction and operation of the steam engine under the head of the mechanic arts or as a part of the science of mechanics, and yet the dynamo-electric machine and the electric motor have as great, if not a greater, reason to be treated under the electric arts and sciences; for these pieces of electric apparatus have reached such a stage that it is now possible to design dynamo-electric generators of over 5,000 horse-power capacity, which, when constructed, require no change, but are ready at once to convert mechanical energy into electric energy on this great scale. Even to-day such an achievement could scarcely be equalled by the most advanced mechanical or steam engineer.

The construction and operation of dynamos and motors properly belong to the electric arts and sciences.

I

DYNAMOS

CHAPTER I

DYNAMO-ELECTRIC MACHINES

> "All dynamos are based upon the discovery made by Faraday, in 1831, that electric currents are generated in conductors by moving them in a magnetic field."—*Dynamo-Electric Machinery:* S. P. THOMPSON

A DYNAMO-ELECTRIC machine is any machine by means of which mechanical energy is converted into electric energy by magneto-electric induction. The term dynamo-electric machine is also applied by some to any machine by means of which electric energy is converted into mechanical energy by magneto-electric induction. Machines of the first class are generally called generators; those of the second class, motors. For example, S. P. Thompson, in his excellent work entitled "Dynamo-Electric Machines," defines the term as follows: "A dynamo-electric machine is a machine for converting energy in the form of mechanical power, into energy in the form of electric currents, or vice versa, by magneto-electric induction; the operation being, in general, that of setting conductors, usually of copper, to rotate in a magnetic field."

Definition of dynamo-electric machine.

S. P. Thompson's definition of dynamo-electric machine.

Any dynamo-electric machine is capable of either furnishing electric currents when driven by mechanical power from a steam engine, waterfall, or some other external source of similar power, or furnishing mechanical power when supplied with electric currents from a voltaic battery, another dynamo,

Continuous-current and alternating-current dynamos.

Two great classes of dynamos.

or any other electric source. Dynamos can be divided into two great classes; viz., continuous-current dynamos, or those in which the electric current they generate flows in one and the same direction, and alternating-current dynamos, in which the currents they generate rapidly flow alternately in opposite directions.

A dynamo-electric generator, or dynamo-electric machine, as ordinarily constructed, consists essentially of the following parts; viz., of the armature, the field magnets, the commutator, and the collecting brushes.

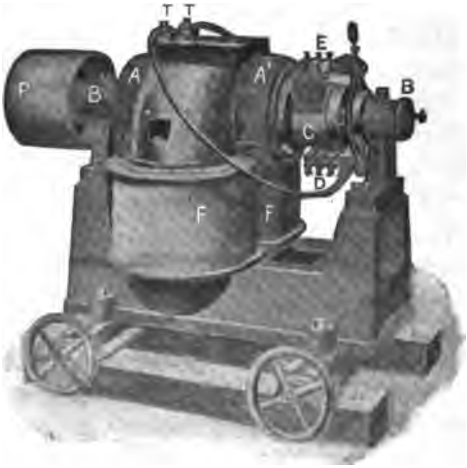


Fig. 1.—Dynamo-Electric Machine. Belt-driven type.

Armature of dynamo-electric machine.

Generally speaking, the armature of a dynamo-electric machine, in which E.M.F.'s are generated, consists of that part of the machine which is rotated or driven by the expenditure of mechanical power. In some forms of machines, however, the armature remains at rest, either the magnetic flux or the magnets that produce the magnetic flux being rotated. The armature generally consists of a number of copper conductors placed on the outside of a drum, ring, disk, or cylinder, which is firmly mounted on a shaft provided with a pulley, so that it can be given rapid rotation by means of a belt. Sometimes, however, the armature shaft is connected directly with the driving steam engine, or turbine water wheel. This gives rise to two types of dynamo-electric machines, called respectively a belt-driven dynamo and a direct-driven dynamo. In the machine represented in Fig. 1, the armature is shown at A A. This machine belongs to the belt-driven type, and is provided with a pulley, as shown. The armature shaft is supported on bearings at B B.

Belt-driven and direct-connected dynamos.

The field magnets of a dynamo-electric machine constitute the part of the dynamo in which the magnetic flux is generated. The field magnets furnish the magnetic flux which produces the currents in the conductors on the armature when they are rotated so as to cut it. The field magnets consist generally of masses of iron on which are wound coils of insulated copper wire. They are provided with soft iron masses, called pole pieces, which are shaped so as to conform to the outline of the armature, which rotates between them. It is by means of these pole pieces that as much as possible of the magnetic flux is caused to pass through the rotating armature, and so generate E.M.F.'s in its conducting wires. The field magnets are represented by F F. The commutator C consists of means for collecting and directing the currents produced by the E.M.F.'s generated in the revolving armature. This part is called the commutator, because it commutes all

Dynamo field magnets.

Pole pieces of dynamo.

Commutator of dynamo.

these currents, or causes them to flow in one and the same direction.

Collecting brushes of dynamo.

The brushes or collectors of a dynamo-electric machine consist of bundles of wires, plates of carbon or copper, or sheets of metallic gauze, that are pressed against the surface of the commutator. Collecting brushes are shown at E D, and are connected as there indicated with the terminals, T T, of the machine.

The value of the E.M.F.'s produced by a dynamo depends, as in all other cases of electro-dynamic induction, on the rate at which the loops of conducting wires on the armature are filled with or emptied of magnetic flux. Consequently, in the dynamo, the value of the E.M.F.'s generated may be increased by increasing the speed of rotation of the armature, by increasing the amount of magnetic flux which passes through the circuit of the machine, or by increasing the number of conducting loops on the armature.

Why increased E.M.F.'s can not be practically obtained by increasing speed of armature rotation.

It would not be practicable, in all cases, to increase the E.M.F.'s by merely increasing the speed of rotation of the armature, since to double the value of the E.M.F.'s by such means would necessitate doubling the speed of rotation, and this, generally, would carry the speed far beyond safe limits. We can, however, obtain such increased value either by increasing the number of turns of conducting wire on the armature, or by increasing the quantity of magnetic flux that passes through the armature.

The total value of the E.M.F.'s generated in an armature circuit is equal to the sum of all the separate E.M.F.'s produced in that circuit, provided all the separate loops that are generating E.M.F.'s are properly connected in series with one another; in this way, therefore, it is possible to obtain almost any E.M.F. that may be required, especially if, at the same time, both the speed of rotation and the amount of magnetic flux passing through the armature are increased. The increased magnetic flux passing through the armature can, within certain limits, be obtained by increasing the number of turns of insulated wire on the field magnets, as well as by increasing the amount of iron in the core of such magnets.

Other ways of increasing value of E.M.F.'s generated in armature coils.

The output of a dynamo is the electric activity it produces at its terminals, that is, the output is the available electric activity produced by the machine. The intake is the mechanical energy the machine requires to drive it. The efficiency of a dynamo is the relation that exists between the output and the intake, and is equal to the output divided by the intake. Since there are always losses in the conversion of mechanical into electric energy, the output must always be smaller than the intake. Consequently, the efficiency is always less than unity.

Output and intake of dynamo

Efficiency.

It may be well here to explain briefly just what is meant by work and activity. By work is meant the expenditure of some force acting through a distance, as, for example, when a man raises his own weight through a certain vertical height by mounting a stairway. Here the man expends his muscular energy in order to raise his weight through the vertical distance between the bottom and the top of the stairway. A convenient unit of work, called the foot-pound, is equal to the amount of work that is done when a weight of one pound is raised through

Work and activity defined.

Unit of work.

a vertical distance of one foot, against the force of gravity. The rate-of-doing work, or of expending energy, is called the activity or power. It is evident that a man weighing one hundred and fifty pounds, in raising his weight by mounting a stairway through a vertical distance of one hundred feet, will perform the same amount of work whether he does this in one minute or in ten minutes. But it is clear that the rate at which he expends his energy will be ten times greater in the first instance than in the second; or, in other words, the activity or the power is ten times greater in the first instance than in the second. A convenient unit of activity or power is the foot-pound-per-second. As this is a rather small unit, a larger unit, called the horse-power, is generally employed, the horse-power being equal to an activity of five hundred and fifty foot-pounds-per-second.

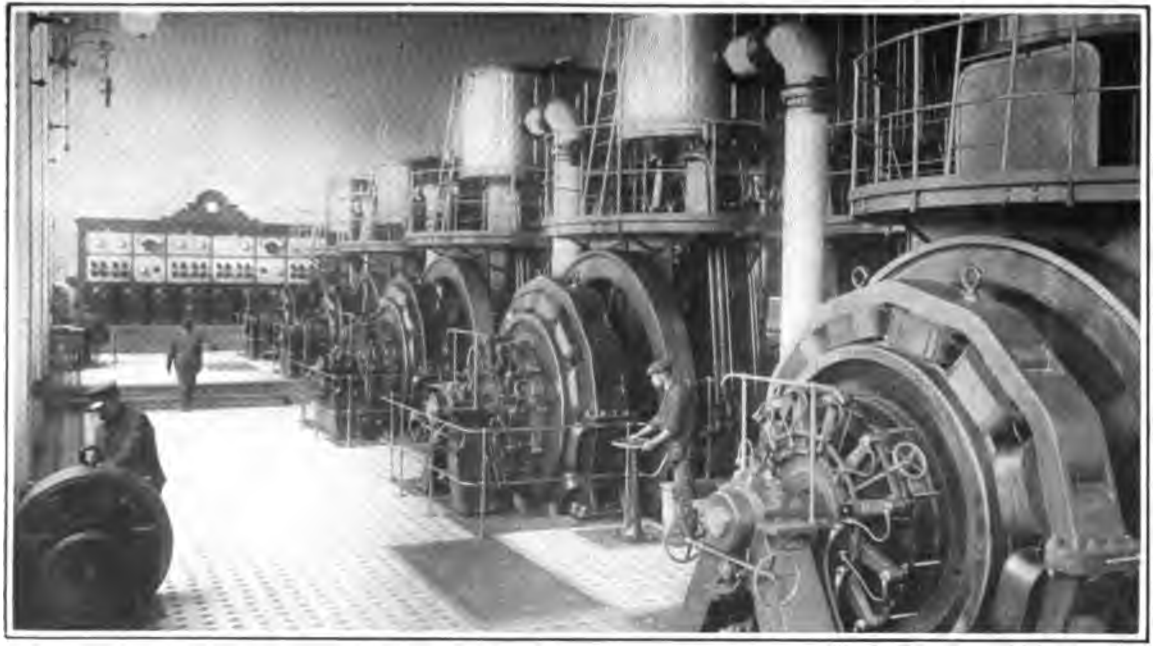
Unit of activity or rate-of-doing work.

Horse-power.

We will be better able to understand the relations existing between the ordinary units of work and activity and the electrical units of work and activity from the following consideration: When a pound of water falls from a reservoir through a vertical distance of one foot, it does an amount of work equal to one foot-pound, since this is the amount of work that would have to be done in order to raise the water vertically through a distance of one foot against the force of gravity. In a similar manner, we may conceive that when one coulomb of electricity passes through a circuit under a pressure of one volt, the amount of work that is expended in such circuit will be equal to one volt-coulomb; this is sometimes called the joule, and is equal to the amount of electric work done, or the energy expended, in order to raise the potential of one coulomb of electricity one volt. The practical unit of elec-

Relations between mechanical and electric units of work and activity.

The volt-coulomb, or joule.



ELECTRIC LIGHT AND POWER PLANT OF THE GERMANIAWERFT

This illustration gives a good view of a well-appointed modern light and power plant. Multipolar dynamos are direct-connected to the engines which run them. The switchboard is seen at the back. This is at the works of the Germaniawerft, Kiel, Germany

tric work may, therefore, be called the volt-coulomb, or the joule, the joule being equal to 0.738 foot-pounds.

The practical unit of electric activity or power is the joule-per-second, or, as it is sometimes called, the watt, after James Watt, who did so much to improve the steam engine during the years of its early existence. Since an ampère is equal to a coulomb-per-second, instead of regarding the watt as a rate of doing electric work equal to one coulomb-per-second, we can regard it as equal to one volt-ampère. The watt is, approximately, equal to $\frac{1}{746}$ of a horse-power.

Joule-per-second, or the watt.

Practical unit of electric activity.

The output of a dynamo, as well as its intake, is expressed in watts. Since one watt is a very small unit of activity in power, being only equal to the $\frac{1}{746}$ of a horse-power, a larger and more convenient unit of electric activity called the kilo-watt, or one thousand watts, is generally employed in practice. A kilo-watt is equal to 1.34 horse-power.

Definition of kilo-watt.

Dynamo-electric machines can be conveniently divided into various classes, according to a variety of circumstances. For example, they may be divided into constant-potential dynamos, or those in which a constant potential or pressure is maintained at the dynamo terminals, irrespective of the work done in the external circuit; and constant-current dynamos, or those in which a constant strength of current is maintained in their circuits, notwithstanding variations in the external circuits. Again, dynamo-electric machines may be divided into classes, according to the source of their magnetic flux; for instance, they may be magneto-electric machines, in which the flux is obtained from per-

Constant-potential and constant-current dynamos.

Magneto-electric machines.

Separately excited dynamos.

Self-excited dynamos.

Series-wound, shunt-wound, and compound-wound dynamos.

manent magnets, or the flux may be obtained from electro-magnets, in which case the machines may be separately excited, where the electro-magnets are excited by currents from a source outside of the machine, or they may be self-excited, that is, those whose field magnets are supplied from currents from the armature of the machine. Self-excited machines may be subdivided into series-wound machines, in which the circuit of the field magnets is connected in series with the circuit of the armatures; and shunt-wound machines, or machines that have their field magnets connected with the main terminals, or, in other words, placed in a shunt, or additional circuit, with the external circuit; and compound-wound machines, or those whose field magnets are partly series-wound and partly shunt-wound.

Bipolar and multipolar dynamos.

In addition to the above classes dynamos may be divided into different classes according to the number of poles employed in the field magnets, for example, bipolar machines, are those whose field flux is obtained from field magnets having but two poles; quadripolar machines are those whose field magnets have four poles; sextipolar are those having six poles; octopolar are those having eight poles, etc. All machines whose field magnets have more than two poles are sometimes called multipolar machines.

Arc-light generators.

Incandescent-light generators.

Dynamos may also be divided into different classes according to the character of their armatures. Still another classification is based on the character of the work the dynamo is intended to perform, such, for example, as arc-light generators or dynamos, or those intended to supply currents to arc lights; incandescent-light generators, or those supplying currents to incandescent lights; plating generators, or those intended to supply currents for electro-metallurgical operations; generators for producing the current required to drive motors; telegraphic generators, or those employed for systems of telegraphic communication; therapeutic generators, or those employed by physicians for the purpose of curing diseased conditions of the human body; and welding generators, or those employed for producing the large currents required in systems of heating metals to temperatures at which they can be electrically welded together.

Therapeutic generators.

Among the different dynamos invented by Faraday, one produced by him at a much later date than the disk dynamo already described, consisted of a rectangle of copper wire W, Fig. 2, arranged so as to be capable of rotation around a horizontal axis. In this early form of machine there were no field magnets employed, Faraday having devised the apparatus for the purpose of demonstrating the possibility of generating electric currents by the rotation of a conducting loop in the earth's field. When this conducting loop was rotated about a horizontal axis placed east and west, and rotated in the earth's flux,

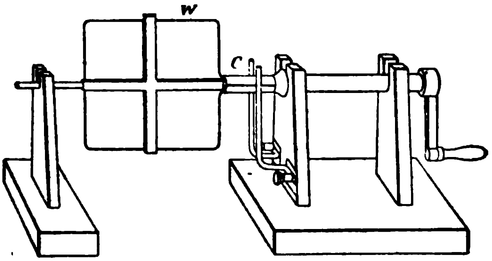


FIG. 2.—Faraday's Simple Conducting Loop Dynamo. Note that as the rectangular circuit W is rotated in the earth's flux, it is alternately filled with and emptied of flux, and therefore has E.M.F.'s generated in it. These E.M.F.'s are commuted, or caused to flow in one and the same direction, by means of the two-part commutator at C.

Faraday's conducting loop dynamo.

E.M.F.'s and currents were generated in it. When suitably provided with field magnets and a commutator, this early machine corresponds to a type of dynamo generally employed to-day. We will, therefore, examine somewhat closely into the general character of the E.M.F.'s it produces by dynamo-electric induction when rotated in a bipolar field.

Directions of currents generated by rotation of conducting loop in bipolar field.

Take, for example, the single loop of conducting wire, A B C D, Fig. 3, so mounted as to be capable of rotation on a horizontal axis between the poles S and N of the magnet in the direction indicated by the large feathered arrow. Suppose the loop be placed at first in the vertical plane directly midway between the poles of the magnet. In this position the number of lines of magnetic force that pass through it from right to left, *i.e.* from the north to the south magnet pole, will be a maximum, and, as the loop moves through 90° to the horizontal position, the lines of magnetic force will pour out of the loop and will continue to decrease to zero or nothing until the horizontal position is attained. On continuing the rotation the number of lines of force again begin to pass through the loop, but now in the opposite direction, and the number so passing

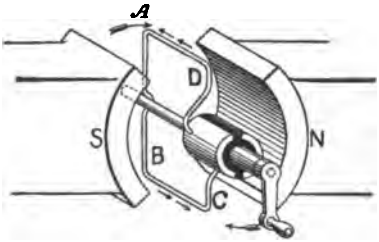


FIG. 3.—Dynamo-Electric Induction in a single Conducting Loop. Note that the loop when in a vertical position contains the greatest amount of magnetic flux. When it begins to move the flux begins to pour out of it.

continue to increase until the loop has moved through 90° additional, or 180° from its first position, and is again in the vertical position. Since these latter lines of force have a negative direction to the first, they induce E.M.F.'s in the same direction as at the first. Therefore, during the motion of the loop from its position of rest in the vertical position through one-half turn, until it again reaches the vertical position, the E.M.F.'s generated will have the same direction. During the last half turn, however, until the loop again reaches the position it had when started, they will be oppositely directed. The direction of the E.M.F.'s and current in the loop will be that indicated by the direction of the small arrows; viz., from the back to the front in the part of the loop which is rising to the left, and from the front to the back in that part which is descending on the right. During the motion of the loop through the remaining half turn, the E.M.F. and current will be oppositely directed. Consequently, electric currents will flow through the rectangle during each complete rotation in the magnetic field, in one direction through the first half of its rotation, and in the opposite direction through the remaining half of its rotation.

Action of two-part commutator.

If it be desired to produce direct currents from any machine, that is, currents that flow in one and the same direction, a commutator must be used for the simple armature shown in Fig. 3. Such a commutator would consist of a hollow cylinder, cut into two equal parts and mounted as shown in Fig. 3, on the outer surface of a cylinder of hard rubber, or other suitable insulating material. One of the ends of the conducting loop is connected with one of these metallic segments, and the other end with the other segment. If now, collecting brushes, B B′, Fig. 4, be caused to press against these commutator segments in the vertical line of the gap between the poles, corresponding to the vertical gap between the commutator segments, the currents generated in the loop will be caused to flow in one and the same direction, since the ends of the loop are connected respectively with the positive and negative brushes only as long as these ends remain positive and negative, that is, during one-half rotation. As soon as the ends of the loop become respectively negative and positive, that is, at the beginning of the second half of the rotation, the segments with which they are connected are caused by the rotation to change over to the negative and positive brushes of the commutator, respectively. Consequently, the brushes continue respectively positive and negative for rotation after rotation, or the current is caused to flow in one and the same direction through the external circuit connected with the collecting brushes.

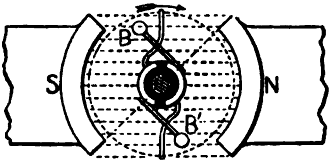


Fig. 4.—Action of Two-part Commutator. Note the fact that each half-segment of the two-part commutator only remains in contact with the same collecting brush for one-half of a complete rotation.

Faraday thus describes the action of the simple two-part commutator shown in the two preceding figures:

Faraday's two-part commutator.

"The apparatus which carries these rectangles, and is also the commutator for changing the induced currents, consists of two uprights, fixed on a wooden stand, and carrying above a wooden horizontal axle, one end of which is furnished with a handle, while the other projects, and is shaped as in Fig. 4 (our Fig. 5. It may there be seen that two semi-cylindrical plates of copper, *a*, *b*, are fixed on the axle, forming a cylinder round it, except that they do not touch each other at their edges, which therefore leave two lines of separation on opposite sides of the axle. Two strong copper rods, 0.2 of an inch in diameter, are fixed to the lower part of the upright *c*, terminating there in sockets with screws for the purpose of receiving the ends of the rods proceeding from the galvanometer cups: in the other direction the rods rise up parallel to each other, and, being perfectly straight, press strongly against the curved plates of the commutator on opposite sides; the consequence is that, whenever in the rotation of the axle, the lines of separation between the commutator plates arrive at and pass the horizontal plane, their contact with these bearing rods is changed, and, consequently, the direction of the current proceeding from these plates to the rods, and so on to the galvanometer, is changed also. The other or outer ends of the commutator plates are tinned, for the purpose of being connected by soldering to the ends of any rectangle or ring which is to be subjected to experiment."

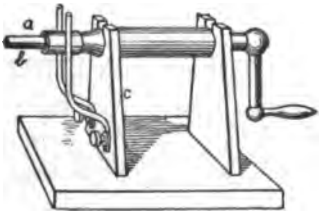


FIG. 5.—Faraday's Description of Action of Two-part Commutator.

Faraday's explanation of action of commutator.

In actual practice the points on the surface of the

Why a lead must be given to collecting brushes.

commutator, where the collecting brushes must rest, in order best to carry off the current generated, do not lie in the vertical line coinciding with that of the gap between the magnet poles. The reason for this change of position is that during rotation the direction of the lines of magnetic force is considerably changed, owing to the action of the magnetizing current in the armature, so that, instead of the line of greatest density of magnetic flux being situated directly along the horizontal line joining the centres of the two opposite magnet poles, it is considerably shifted from this position, as is indicated in a representation of such lines of force taken by means of iron filings, and shown in connection with Fig. 6.

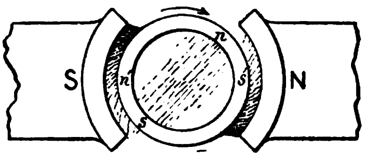


Fig. 6.—Distortion of Magnetic Flux in Bipolar Field, showing why the collecting brushes must be displaced in the direction in which the armature is being turned or rotated.

Diameter of commutation.

It is for this reason that the commutator brushes must be given a lead, or displacement in the direction of rotation, so that the diameter of commutation is considerably changed. As shown in the figure, this change in the diameter of commutation has carried it nearly at right angles to its theoretical position.

Armature loops.

In order to increase the value of the E.M.F.'s generated in the conducting loop, more than a single turn of wire is generally employed, as is shown at the left-hand side of Fig. 7, where two turns are represented. In practice a number of turns are generally employed.

Drum and ring armatures.

Series and parallel connection of armature coils.

The armature coils or conducting loops of wire are wound on the surface of a cylinder, drum, or ring. Such armatures are called cylindrical, drum, and ring armatures respectively, from the shape of their cores. An armature loop or coil consisting of five separate turns of wire wound on the surface of a ring-shaped core is shown at the right hand of Fig. 7. Generally, however, instead of employing only a single coil on ring armatures, two separate coils are wound on opposite sides of the ring, as shown in Fig. 8. Such coils may be connected either in series or in parallel. As shown in Fig. 8, the connection of the two opposite coils is in parallel.

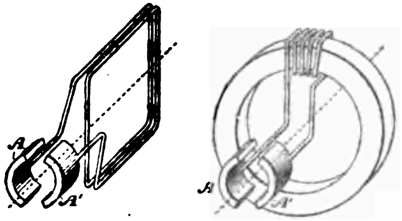


FIG. 7.—Two-part Commutator connected respectively to two and five conducting armature loops. The commutator segments are represented at A and A'.

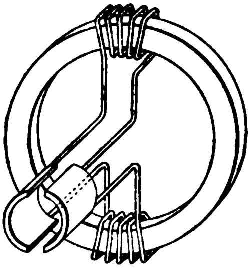


FIG. 8.—Multiple connection of two separate coils to segments of Two-part Commutator. Note the direction of the winding of the two diametrically opposite coils.

How commutated currents are obtained of practically uniform strength.

Where a two-part commutator is employed, although the currents generated in the coils are caused to flow in one and the same direction, yet they are not of the same strength throughout all the rotation of the armature. If, for example, a single pair of coils be employed, the current strength would undergo marked changes during each rotation of the armature, since twice during each rotation the current would begin with no strength, and would rise to a maximum value, and then decrease again to no strength. In order to avoid the variations resulting in the strength of the current generated, commutators are employed containing a greater number of segments than the two-part commutators represented in the preceding figures. If, for example, the coils C C and C′ C′, Fig. 9, wound on a drum core, be connected as shown to the segments 1, 2, 3, and 4, of the four-part commutator, and brushes B and B′ be placed as indicated, the coils will be connected in a single closed circuit. Now, as these coils are arranged so that one set will be in the position of best action, while the other set are in the position of poorest action, since they are connected in a single circuit, they will produce a current

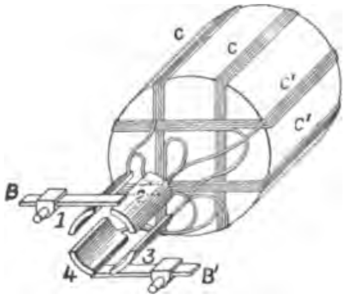


Fig. 9.—Four-part Commutator for Drum-armature, showing the connections of the coils to the segments of the four-part commutator.

Parallel connection of coils on ring-armature.

that will have less marked changes in its strength than if a two-part commutator were employed. Two different sets of coils wound on a ring-armature, and so joined or connected as to be in parallel, are represented in Fig. 10. In actual practice a great number of separate coils are wound on the surface of armature cores of different shapes, and connected to commutators containing a number of separate segments that correspond to the separate coils and their connections. In this way a current of practically uniform strength, as well as uniform direction, is obtained.

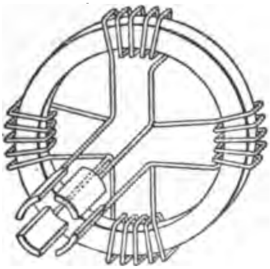


FIG. 10.—Parallel connection of coils on Ring-Armature to segments of Four-part Commutator.

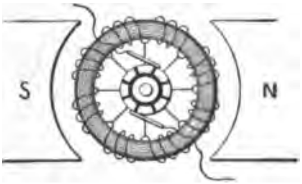


FIG. 11.—Connections of Gramme-wound Ring-Armature in Bipolar Field.

Sometimes ring armatures are wound with a number of separate coils, as in Fig. 11, which rep-

Pacinotti or Gramme-wound ring armature.

resents a form of armature first introduced by Pacinotti, and afterward greatly improved by Gramme, and now generally known as the Gramme armature. In this armature separate coils are wound on the surface of the ring and connected in series. The points of connection of contiguous coils are then joined to separate segments of a multi-part commutator, containing, therefore, as many separate segments as there are points of connection between the separate coils. The brushes in this figure are given a lead, thus showing that the diameter of commutation has been displaced during rotation, in the manner already described.

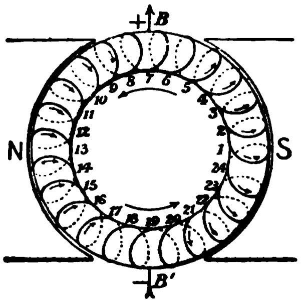


Fig. 12.—Gramme Ring-Armature in Bipolar Field, showing the direction of the currents induced in the separate coils.

Direction of currents in Gramme ring-armature coils.

During the rotation of a ring armature in a bipolar field, the E.M.F.'s are generated in the coils in the direction indicated by the small arrows of Fig. 12. Here the coils are numbered, consecutively from 1 to 24. Practically no currents are generated in coils 6, 7, and 8, and 18, 19, and 20, but the E.M.F.'s, and consequently the currents, produced in all the active coils on the right-hand side of the vertical line B B', the diameter of commutation, flow in the same direction, while those on the left-hand side are oppositely directed. Consequently, if collecting brushes are placed against the segments in the position shown in Fig. 12, these oppositely directed E.M.F.'s and currents will act as indicated in Fig. 13, which shows two series-connected voltaic batteries coupled together in parallel; or, in other words, B and B′ become respectively the positive and the negative terminals of the series.

Voltaic analogue

A Gramme-ring dynamo, as actually constructed by the inventor, is represented in Fig. 14. Here the ring armature is rotated in the bipolar field produced by a permanent horseshoe compound magnet. It is provided with a commutator consisting of many separate segments. A single pair of collecting brushes carry off the currents produced in the armature to the external circuit, in which they are to be employed. In the particular form of dynamo represented in this figure, the armature is rotated by hand, but in large Gramme-ring machines, a steam engine, capable of exerting a mechanical power of many horse-power, is required.

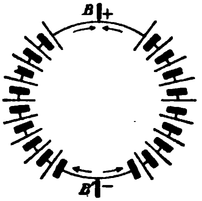


FIG. 13.—Connection of two Series-connected Voltaic Batteries, showing analogy to connection of series-connected coils on opposite halves of Gramme-wound armature.

Hand-driven magneto-electric machine—Gramme type.

A great number of separate commutator segments are generally employed in modern Gramme-wound ring-armatures. For example, the armature in Fig. 15 contains many separate coils wound on the surface of a ring-shaped core connected with the

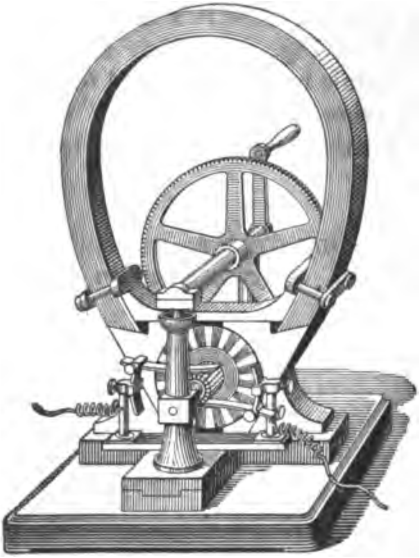


Fig. 14.—Gramme Magneto-Electric Machine. Hand-driven. The hand-driven gear-wheel imparts a rapid rotation to the armature.

Gramme-wound ring armature.

separate commutator segments. In this figure is shown the arrangement of the commutator end of the armature, as seen on the right-hand side of the

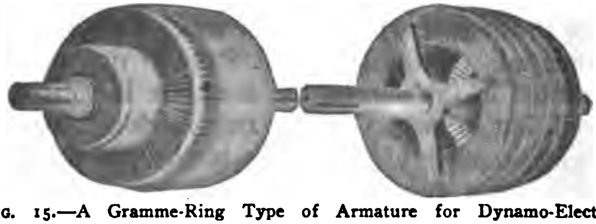


Fig. 15.—A Gramme-Ring Type of Armature for Dynamo-Electric Machine.

figure, and of the pulley end as seen on the left-hand side. Here the pulley has been removed so as to enable the details of the construction and winding to be more readily examined.

Bipolar dynamo.

A dynamo of the bipolar type is represented in Fig. 16. Here a pulley P′ is provided so that the armature A can be rotated betwen the poles P, P, and the field magnets M, M. A pair of collecting brushes B rest against the surface of the commutator at C, at points diametrically opposite each other. The positive and negative brushes, respectively, consist of three separate brushes, each electrically connected together. The collecting brushes are supported by a device called a brush holder, by means of which they can be shifted to different parts of the commutator surface. The axis of the shaft on which the armature and commutator are mounted is provided with bearings that are suitably oiled to prevent friction. The main terminals of the machine are seen at T, T, connected to the brushes,

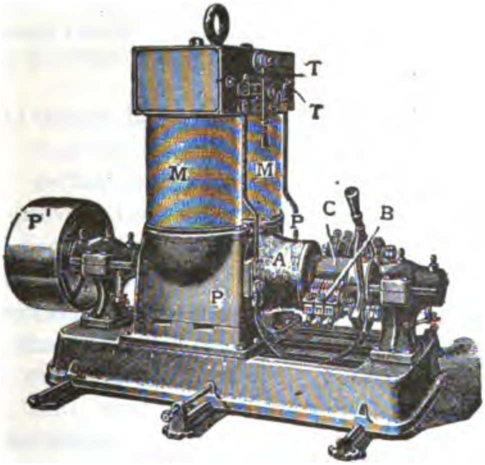


FIG. 16.—Bipolar Dynamo-Electric Machine. Note the manner in which the supports for the driving shaft and the pole pieces of the magnet frames are mounted on the cast-iron base plate.

as is seen in the figure, by means of flexible cables consisting of many separate strands of copper wire. These cables pass from the brushes to the terminals in the manner shown in the figure. The machine is mounted as shown on a heavy base plate.

CHAPTER II

SOME LOSSES IN DYNAMOS

> "The difference between the value of the output and intake is to be traced to certain losses which occur, whereby energy is uselessly expended in the machine, and does not appear in the external circuit."—*Electrical Engineering Leaflets:* HOUSTON AND KENNELLY

NO matter how well a dynamo-electric machine may be designed and constructed, there are certain losses which necesssarily occur and which prevent the output from equalling the intake. In the first place, the current which flows through the coils of wire on the field magnets and the armature necessarily produces a certain amount of heat, due to the resistance offered by the conductor. The energy expended to produce this heat is lost to the circuit, and, consequently, renders the output less than the intake.

Output of dynamo necessarily less than its intake.

The amount of heat produced in any circuit by an electric current flowing through it and overcoming the resistance due to the length and area of cross-section and the character of the material of which it is composed, and generally called its ohmic resistance, is directly proportional to the amount of this resistance, and to the square of the current strength. If a current of a given strength, in passing through a circuit of a given resistance, produces a certain amount of heat, should the resistance be doubled and the current strength remain the same, the amount of heat produced will be doubled. If,

Ohmic resistance of circuit defined.

Effect of ohmic resistance and current strength on quantity of heat developed in circuit.

however, while the resistance remains the same, the current strength be doubled, the amount of heat will be increased fourfold. This loss of energy of the current is dissipated as heat.

Eddy, Foucault, or parasitical currents.

Besides the loss due to the ohmic resistance of the circuit, there is a loss produced by the fact that the masses of metal in a dynamo have E.M.F.'s, and, consequently, currents, produced in them, due to the variations in the intensity of the magnetic flux which passes through them. In this way electric currents are set up in the iron masses of the pole pieces, and the armature cores, as well as in the mass of the copper conductors on the armature. Such electric currents are called eddy or Foucault currents. Since they produce no useful effects in the machine they are sometimes called parasitical currents. As we shall shortly see, such currents not only diminish the output of the machine, from the fact that they require an expenditure of energy to produce them, but they also act in other ways to decrease this output.

Eddy currents generated in pole pieces of dynamos.

In the production of eddy currents, as in the production of the useful currents set up in the armature, the strength of the currents depends on the rate of change at which the magnetic flux passes through the metallic masses. Consequently, when eddy currents are set up in the pole pieces, they will possess the greatest strength in those parts of the poles pieces where the greatest variation in the magnetic strength occurs. This will be near those corners of the pole pieces from which the armature is moved during its rotation. A graphic representation of Foucault currents in the pole pieces of a dynamo is shown in Fig. 17. Such currents penetrate into the mass of iron, though not to a very great depth. The pole pieces of some types of dynamo are laminated so as to prevent these currents from obtaining any considerable strength; or, instead of laminating the pole pieces, these masses or iron are grooved or slotted for the same purpose.

Lamination of armature or other cores.

In the same manner the setting up of powerful eddy or Foucault currents in the iron cores of the armatures may be avoided as follows: Instead of forming these of one continuous mass of iron, they are laminated or built up of separate pieces. This is done by placing together a number of separate sheets, plates, or wires, so as to produce a core of the required shape. The separate wires or bundles were originally insulated from one another by sheets of paper, or by varnish applied to the outside. The use of paper sheets was objectionable because it not only introduced into the mass a substance which was not as readily penetrated by the magnetic flux as was the iron, but also, unlike the iron, was unable to add any of its own flux to the circuit. It has been found in practice that the thin coating of oxide of iron that is formed on the thin plates of sheet iron employed for the separate laminæ, during

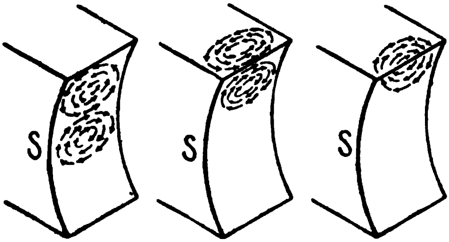


Fig. 17.—Representation of Eddy Currents generated in Pole Pieces of Dynamo. Note that these currents flow in short closed circuits of comparatively small resistance. Hence the current strength is large and the heating effects pronounced.

Separate wires of cores generally not especially insulated manufacture, afford a sufficient insulation, without the introduction of either paper or varnish.

Direction of lamination.

The direction of the laminations of the core of the armature should be in planes at right angles to the armature coils, or in planes parallel to the direction of the lines of magnetic force or parallel to the motion of the armature. In other words, in armature cores the lamination should be, in general, in planes at right angles to the currents that would otherwise be generated in them. For the same reason the pole pieces should be divided in planes perpendicular to the direction of the currents in the armature wires.

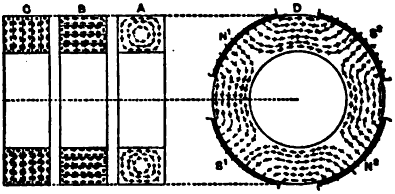


FIG. 18.—Diagrammatic representation of effect of lamination of armature cores on the production of eddy currents. Note that at B the armature core is formed of a spiral winding of sheet-iron ribbon, while at C the armature is laminated by being built up of sheet disks.

Manner in which lamination of armature core influences the setting up of eddy currents.

When the armature core is laminated in this manner, the eddy currents are confined to the section of each disk, sheet, plate, or wire. If A, Fig. 18, represents an armature core formed of a solid mass of iron, and mounted so as to be capable of rotation in the quadripolar field N^1, S^1, N^2, S^2, then the general direction of the magnetic flux through the mass of iron will be that represented by the arrows in the cross-section of this solid iron core. As shown at A, the arrows indicate the direction of the eddy currents in the solid mass. At B is shown a cross-section where laminations are made in a direction parallel to the axis of the armature. Here the arrows show the direction of the eddy currents as being limited to the cross-section of each separate part of the laminæ. If in such a core the magnetic flux passes through the ring from the top to the bottom, a considerable resistance will be experienced while the flux is endeavoring to pass through the minute air spaces between the separate laminæ. In the cross-section shown at C, the armature is laminated in planes perpendicular to the axis, that is, is built up of separate sheet disks. Here, as before, the eddy currents are limited to the cross-section of each lamina, while the magnetic flux can pass directly through the mass of each lamina.

Core disks.

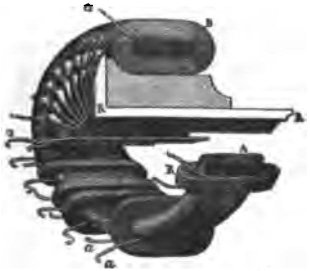


Fig. 19.—Gramme-Ring Armature. Showing laminated core of soft iron wire, and some of the separate armature coils in place on the core. Note the core of iron wire shown at A and B.

Armature core of Gramme-ring.

The lamination of the armature core of a Gramme-ring is shown in Fig. 19. Here the core is formed by winding a long soft iron wire in the form of a closed ring, whose outline shall be that of the armature core, and whose cross-section is that indicated in the figure at A and B, where the Gramme-ring has been cut in order to show the details of its construction. Here, as will be seen, the separate coils are wound around the ring so that the direction of the armature winding is directly across the direction of the iron wire of the core.

Lamination of core of cylindrical armature.

The lamination of the core of a cylindrical armature is shown in connection with Fig. 20. Here the core is built up by assembling a number of core disks on the axis or armature shaft, so that, when assembled, they shall form an iron core divided or laminated in planes at right angles to the axis of rotation.

Besides the loss in the output of a dynamo-electric machine, due to the wasteful expenditure of energy required to set up the eddy currents, there is a loss caused as follows: When the eddy currents are powerful, they tend to set up a magneto-motive force that opposes the production of magnetic flux by the field magnets, so that the presence of powerful eddy currents in the armature core may thus shield some of the conductors in the armature from the magnetic flux, and, therefore, decrease the amount of useful current produced in the armature. Moreover, in addition to this, the increase in temperature of the armature core, produced by the presence of eddy currents in it, raises the temperature

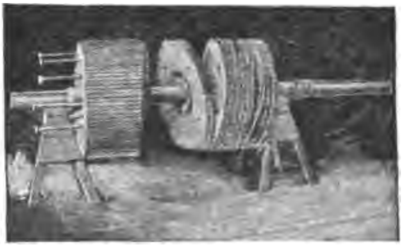


FIG. 20.—Laminated Armature Core, formed by separate core disks, mounted on the armature shaft. Here the laminations are at right angles to the wire in the armature coils.

Decrease of magnetic flux in armature occasioned by eddy currents in armature core.

of the conductors on the armature, and thus, by increasing their resistance, increases the amount of loss due to the passage of the current through the armature wire in overcoming its ohmic resistance.

Loss due to heating of armature coils by eddy currents.

It is a mistaken idea that the armature of a permanent magnet is not to be withdrawn suddenly from the poles lest such sudden withdrawal weaken its strength. On the contrary, the more suddenly the armature is withdrawn, the better will it be for the strength of the magnet; for, when it is suddenly removed, the magnetic flux, produced by the Foucault currents that are thus set up tends to increase the strength of the magnetism. Silvanus P. Thompson gave the following explanation of this effect at the International Conference of Electricians, held in Philadelphia, in 1884:

Magnet strengthened by the sudden withdrawal of its armature.

"To explain these facts, and their mutual relation, I must relate one other observation which I have made, and which connects both sets of facts. . . . Suppose you take a horseshoe magnet, having the usual armature or 'keeper' of iron. You can purchase such an instrument of any optician, who will probably give you instructions never to pull the armature off suddenly for fear you injure the magnetism. He could not possibly give you worse directions. Take such a magnet and try what the effect really is. Fasten it down upon a board with brass screws, and fix a magnetometer near it—a common compass will answer—and notice how much the magnet pulls the needle round. Then put on the armature, by placing it at the bend of the magnet; draw it slowly to its usual position, and suddenly drag it off. You will find that by this action your magnet will have grown stronger. Do this twenty times, and you will make it considerably stronger. I have made a magnet 1.2 per cent stronger by put-

S. P. Thompson on effect of sudden withdrawal of armature from poles of permanent magnet.

ting on the armature very gently and pulling it off suddenly. If you reverse the operation, by letting the armature slam suddenly against the poles and then detaching it gently, you will find that the magnetism will go down. I have made magnets lose 1.3 to 2.1 per cent in this way. Why does this occur? How does it explain the two phenomena noticed just now?

Application of Lenz's Law to the problem.

If you suddenly take away a piece of iron from a magnet, you do work against the magnetic attraction, and the induced currents which are set up in the iron or steel of the magnet are always (as we know from Lenz's Law) in such a direction as to oppose the motion; that is to say, they are in such a direction as will make the magnet pull more strongly than before. By suddenly detaching the armature, we magnetize the magnet more strongly than before, by means of currents circulating within its own mass and within the mass of the armature. In the reverse motion, when you allow the armature to slam up, there are induced currents which are in such a direction as to oppose the motion of slamming; they, therefore, decrease the magnetism of the magnet. Apply this to the dynamo and to the motor. You magnetize more highly by pulling off the armature. That is precisely what is occurring in the field when the machine is being used as a generator. You are dragging away the armature from

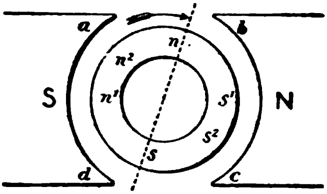
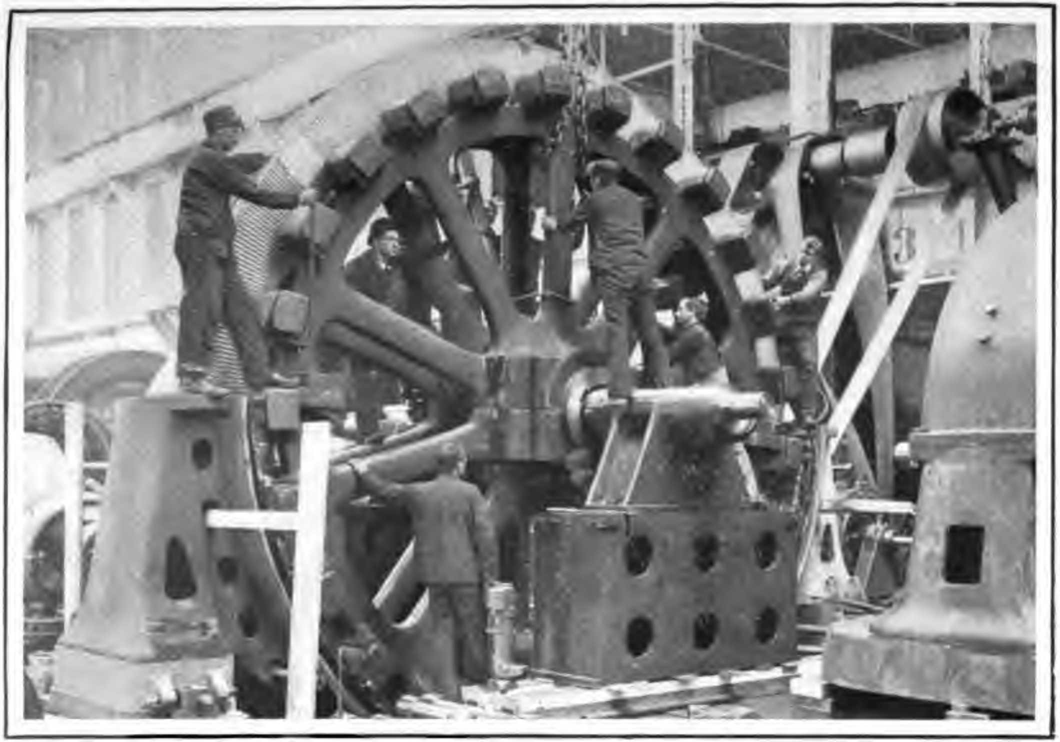


FIG. 21.—Horns of Dynamo, illustrating the poles of a dynamo and motor, respectively, that are strengthened by the sudden withdrawal of armature.



2,000 KILOWATT S.K.C. INDUCTOR ALTERNATOR IN PROCESS OF ERECTION

the active horn *a* (Fig. 21) of the pole-piece, and the effect is to generate induced currents in that horn. It therefore gets hot. So does the other leading horn *c*, for the very same reason. In the case of the motor the horns *b* and *d* are the active ones, and the armature is being continually dragged up toward them, and they get hot from internally induced currents. It is for this reason that in my Cantor Lectures I recommended that pole-pieces should always be laminated. The presence of these induced currents explains the heating effect, and it also explains how it is that when a magneto machine is used as a motor the magnet is weakened, and when used as a generator the magnet is strengthened."

Eddy currents in copper conductors on dynamos.

Another source of loss in a dynamo arises from the setting up of eddy currents in the copper wires or conductors on the armature coils. Such losses are not marked unless the conductor consists of massive bars of copper, as in the case of some forms of dynamos employed to produce the large currents required in electric welding, or in electro-deposition. Here, in order to lessen the strength of the eddy currents, instead of employing single large conductors, each conductor is formed of a couple of smaller wires connected in parallel.

Toothed-core and smooth-core armatures.

In some forms of armature cores there are deep grooves or slots cut in the surface of the armature for the insertion of the conducting wires. Such armature cores are called toothed-core armatures, in order to distinguish them from smooth-core armatures, or those on which the conducting wires are wound directly on the surface of the core. A toothed-core armature is represented in Fig. 22, in three different stages of its construction. At A is

Assembling of separate disks to form laminated core.

represented a laminated iron core, consisting of separate disks. Here all the disks have been assembled, and have formed a laminated core, with spaces between the radial projections. At B is shown the same armature core wound with the separate coils of wire. Here the wires are placed in the grooves or spaces between the projections, while at C the completed armature is represented. The use of a toothed-core armature, however, increases the strength of the eddy currents set up in the pole pieces, because, in the first place, the armature is thus brought by the teeth nearer to the face of the poles, thus permitting any magnetic variation set up in the armature to produce eddy currents in the pole pieces. In the second place, the teeth in their rapid motion past the pole pieces, set up movements of magnetic flux in the polar surfaces, and thus also tend to produce eddy currents.

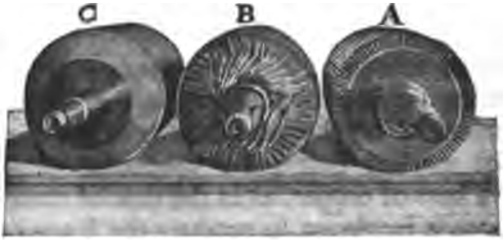


Fig. 22.—Toothed-Core Armature. Completed, wound, and unwound.

Effect of toothed-core armature on eddy currents.

Toothed-core armatures possess a number of advantages over smooth-core armatures. By decreasing the clearance space or air gap between the surface of the armature and the pole pieces, they permit the flux of the field magnets to act more directly on the armature wire, and thus produce a greater output; when sufficiently deep, they protect the armature wire against the formation of eddy currents; moreover, they ensure a better means of maintaining the wires on the armature surface during rotation, since the drag comes on the iron between the wires, rather than on the wires themselves.

Another source of loss in dynamos arises from magnetic friction or magnetic hysteresis in the masses of iron in the armature core. In continuous-current machines this loss occurs only in the armature core. In alternating-current machines, of some types of construction, it also occurs in the field-magnet cores.

Magnetic hysteresis.

In order to magnetize any mass of iron, a certain amount of energy must be expended. As is now generally believed, the iron is magnetized on the passage of an electric current through the magnetizing coils, by the magneto-motive force produced by the current expending its energy in aligning the separate molecular magnets of which the iron is supposed to consist. When the magnetizing force is removed all these molecular magnets tend to return to their original positions. If they did this completely the magnetism of the iron would completely disappear on the removal of the magnetizing current, and all the magnetic energy would be returned or restored to the circuit. In point of fact, however, as we have seen, they all do not return to their original positions. Some of them remain in their new or aligned positions; or, in other words, the iron mass possesses residual magnetism. Consequently, whenever the magnetizing force is rapidly reversed by changes in the direction of the magnetizing current, the mass of iron tends to resist changes in its magnetization; or, in other words,

How iron is magnetized by current.

Meaning of word hysteresis.

the magnetization lags behind the magnetizing force. This lagging is called hysteresis, and the loss so occasioned is called the hysteretic loss. It decreases the output of the dynamo. Hysteretic loss is dissipated in the shape of heat.

Circumstances determining the amount of hysteretic loss.

The amount of the hysteretic loss depends on the value of the magnetization produced in the iron during the changes in its magnetism, as well as on the number of such changes that occur in a given time. It also varies with the quality of the iron. Therefore, in all parts of dynamos, motors, and other apparatus, in which hysteretic loss occurs, care is necessary in the selection of the iron. During the revolution of the armature core in a bipolar field, the direction of the magnetization of the core will undergo two changes during each rotation.

Loss from air churning.

In addition to the preceding losses, there are others which arise entirely from mechanical frictions. One source of such losses is to be found in the friction of the moving parts of the machine; viz., the armature, shaft, pulley and commutator, against the air, thus producing a variety of air churning. This requires the expenditure of energy, and so lowers the output. The amount of this loss is decreased as much as possible by so shaping the different parts as to produce a minimum amount of air disturbance.

Frictional losses at journal bearings.

Another loss by friction is that due to the friction developed by the shaft of the machine as it rotates on its supports or bearings, or, as they are generally called, the journal bearings. The amount of this loss is lessened by employing any suitable lubricating oil or other substance at such bearings, and also by the character of the surface on which the shaft rests. This is generally made of an alloy called Babbitt metal. In large machines oiling is generally obtained by means of devices that automatically supply the oil to the rotating shaft. Such devices are called self-oiling bearings. As represented in Fig. 23, the shaft in its rotation automatically carries the oil from a deep cup, placed below it, by means of hollow tubular rings, and pours it over itself. Any dirt that may get into the oil settles at the bottom of the deep oil cup. When the oil is poured on the shaft it is spread over the bearings along grooves cut into the surface of the Babbitt metal.

Self-oiling journal bearings.

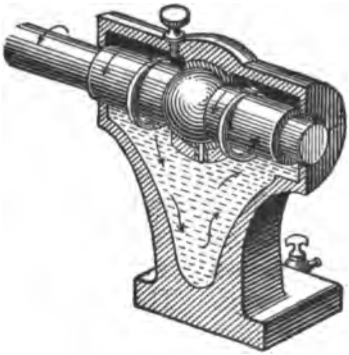


FIG. 23.—Self-oiling Bearing for Dynamo. The curved arrows on the shaft show the direction in which it rotates. The other arrows show the direction of currents in the oil well.

Where dynamos are large a third bearing is sometimes provided outside the pulley. Such three-bearing dynamos are better able to sustain the great strain arising from the weight of the machine and the tension of the belt on the heavy pulley. Great care is necessary in three-bearing generators or dynamos to obtain a true alignment, that is, to ensure

Three-bearing dynamos.

the three bearings being placed in the same straight line; otherwise, even a slight error in adjustment will cause the development of considerable heat at one or more of the bearings. The amount of loss due to friction of the journal bearings will vary with the correctness of the alignment, even when two bearings only are employed. It will also vary with the size of the machine; that is, with the weight on the journal bearings; with the nature of the lubricating material; with the character of the surfaces in contact; with the diameter of the shaft; and with the speed with which the armature rotates. Generally speaking, these frictions increase with the diameter of the journal bearings. Consequently, this diameter is kept as low as possible.

Circumstances affecting the amount of the bearing friction.

Collecting brush friction.

The loss due to the friction of the collecting brushes against the commutator segments varies with the number of the brushes employed, together with the pressure with which they bear on the commutator segments. This loss by friction increases with any increase in the diameter of the commutator, and with the speed of rotation.

Metallic and carbon collecting brushes.

Collecting brushes are composed either of conducting metals, such as copper, or of artificial carbon. The use of metallic brushes tends to roughen or cut the surface of the commutator, while the use of carbon or graphite tends to lubricate the commutator surface, and thus to decrease the amount of its wear. Moreover, machines employing carbon brushes can be readily reversed without difficulty. This is an advantage that is especially serviceable when dynamos are employed as motors.

The use of metallic brushes sometimes causes trouble from the fact that the metallic dust formed by wear against the surface of the commutator segments may cause short circuits in adjoining segments. Dust produced in a similar manner from carbon brushes is less objectionable, on account of the higher resistance it offers. Another advantage arising from the use of carbon brushes is on account of the higher resistance which carbon has for a given length and area of cross-section. This considerably reduces the sparking at the commutator brushes.

Advantages of carbon collecting brushes.

The loss of energy due to the friction of brushes against the commutator segments is generally greater in the case of smaller machines. In large machines this loss is so small as to be practically negligible.

When a dynamo is well designed and properly operated, it can, if of large size, be made with efficiencies as high as ninety-eight per cent. Consequently, the amount of loss due to the abovementioned causes can not, in such cases, exceed two per cent of the total energy required to drive them.

Efficiencies of large dynamos.

Direct-driven dynamos are necessarily limited in their speed to the speed of the engine or turbine with which they are connected. In the case of direct-connected steam dynamos a difficulty necessarily arises from the fact that the dynamo's speed must be limited to the speed of the driving engine. Now dynamos will give their best results when driven at fairly high speeds. On the contrary, the speed of a steam engine is naturally slow. The use of belt driving will, therefore, permit dynamos to be driven at a higher speed, and, consequently, with a greater output. Moreover, the cost of a dynamo

Belt and direct-driven dynamos.

Greater cost of direct-driven dynamos.

and steam engine, when belt driven, is less than the cost of a direct-connected dynamo and engine. As a rule, a high-speed dynamo is less expensive than a slow-speed dynamo, since at high speeds a much smaller quantity of iron and copper are required to be employed in order to obtain a given electric output. Notwithstanding this matter of greater expense, however, direct-driven dynamos of slow speed but of large sizes are gradually coming into general use, by being connected with fairly fast running engines.

Why direct-driven dynamos in large sizes are generally employed.

Where a dynamo is directly coupled to a turbine, the difficulties are much smaller, since a turbine, unlike a steam engine, runs at a speed which is more nearly that of the dynamo. In his excellent book on "Electric Lighting," Prof. Francis B. Crocker thus refers to the matter of the operation of large dynamos directly coupled with steam engines and turbines:

Prof. Crocker on direct-connected dynamos.

"The speed of a dynamo, on the other hand, can be brought down without much reduction in efficiency or other disadvantage, except that the output is decreased, or, what is the same thing, the size and weight are increased for a given output. It is a common thing to hear persons attempt to get around this fact, and confuse or deceive themselves by assuming some form of winding or other arrangement which will give the same output at a lower speed; but we know that a dynamo running at 250 revolutions per minute will give almost exactly twice the output if the speed be increased to 500 revolutions per minute, and in many cases there would be no reason why the higher speed would be objectionable. In other words, it is run at a low speed, and has a diminished output, simply to allow it to be directly coupled to the engine. It may be a proper, or even a very desirable, thing to design dynamos to work at low speed; but the engineer should fully realize that it usually involves some sacrifices of output and efficiency in the machine itself. The usual way to construct a low-speed dynamo is to make the armature of large diameter, thus securing a sufficiently high peripheral velocity; at the same time the armature core is made in the form of a ring, with a comparatively small radial thickness, in order to reduce the weight of iron required. Nevertheless, the frame, shaft, bearings, and other parts of such a machine are necessarily heavier and more costly than if the armature were of smaller diameter and higher speed. The compactness, simplicity, and general advantages of direct coupling are so great, however, that they will often fully warrant the extra cost; and in some cases it may be almost a necessity, as, for example, in the case of a dynamo for use on shipboard, or for other plants in which the space is very limited.

Advantages of direct coupling.

"The direct coupling of dynamos with turbines can be carried out without departing from the normal speed of either machine; that is to say, the ordinary speed of a turbine agrees well with the normal speed of a dynamo of corresponding power. The shaft of a turbine, however, is usually vertical, while that of the dynamo is horizontal; hence, in order to directly couple them, one or the other must be changed from its ordinary arrangement. This can be done either by constructing a dynamo to revolve on a vertical shaft, or a turbine with a horizontal shaft can be obtained. These latter may easily be directly coupled with a dynamo. If the armature is mounted directly upon the shaft of a vertical turbine, the aggregate weight becomes large. An ordinary step-bearing at the bottom is not adequate to carry the weight, and

Umbrella type of electric generator.

will cause much trouble from heating, except in a small plant. Thrust-bearings arranged at various points on the shaft may distribute the pressure sufficiently to carry it properly. In some cases a portion, or all, of the weight is taken off of the bearings, either by magnetic attraction, or by causing the upward pressure of the water in the turbine to balance the weight. A new and successful arrangement consists of a step-or flange-bearing between the surfaces of which oil is pumped under high pressure, so that the weight practically floats.

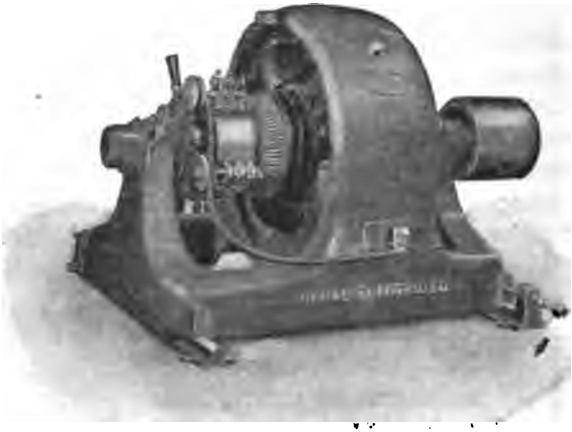


FIG. 24.—Belt-driven Dynamo. General Electric Company's Moderate-speed Type.

General Electric Company's belt-driven generator.

A form of belt-driven dynamo, constructed by the General Electric Company, is represented in Fig. 24. Here the type of armature employed, as shown in Fig. 25, consists of a number of japanned iron laminations, or core disks, which are so shaped as to provide air ducts, extending through the laminations. This construction permits the ready ventilation of the armature. The armature windings consist of copper coils, that are shaped by simple mechanical means before being placed on the core. These armature coils are firmly secured to the core by strong binding wires. The commutator consists of a great number of separate commutator segments, on which carbon brushes rest. The machine is quadripolar, and when driven at a speed of 1,050 revolutions per minute will produce a current of say 240 ampères, at a pressure of 125 volts. Since, as we have seen, the electric unit of activity, or watt, is equal to the volts multiplied by the ampères, a current of 240 ampères at a pressure of 125 volts will produce 240×125=30,000 watts, or 30 kilowatts, generally contracted K.W., a K.W. being equal to 1,000 watts.

The armature coils firmly secured to core by strong binding wires.

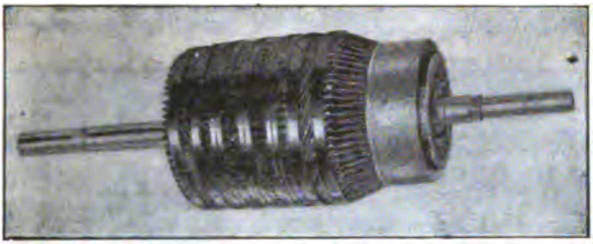


FIG. 25.—Toothed-core Armature, for General Electric Company's Moderate-speed, Belt-driven Dynamo, shown in Fig. 24.

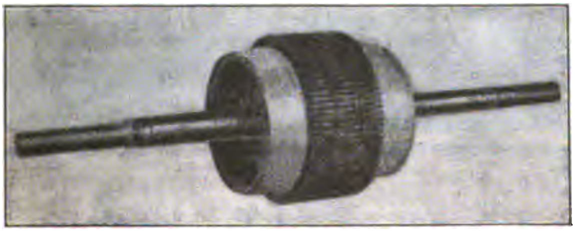


FIG. 26.—Unwound Toothed-core Armature, for General Electric Company's Belt-driven Generator.

Watt and kilowatt.

The armature core employed in this machine is of the toothed-core type, as will be seen from an inspection of Fig. 26.

General Electric Company's direct-connected generator.

A direct-connected dynamo, as constructed by the General Electric Company, is represented in Fig. 27. This machine has eighteen separate magnet poles, and is of the slow-speed type, being designed to run at a speed of one hundred revolutions per minute. At this speed it is capable of producing an output of 800 K.W. at a voltage of 275.

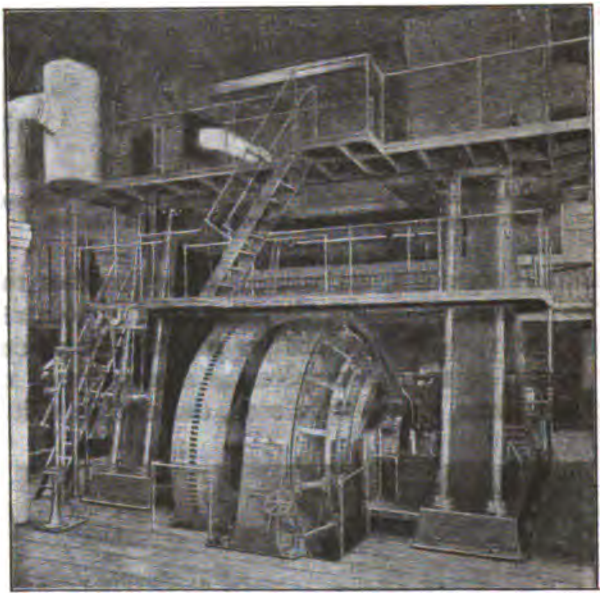


FIG. 27.—General Electric Company's Direct-connected, Slow-speed Dynamo.

As in all large machines, the armature core is thoroughly ventilated, so as to avoid undue increase of temperature. The armature is drum-wound, and is provided with a laminated core composed of separate sheets of soft steel. The armature is a toothed-core armature, the conductors being inclosed in the slots formed in the armature surface. The armature windings consist of straight copper bars of the highest conductivity, connected to the commutator segments by carefully insulated copper leads. Although direct-driven dynamos operate at a lower efficiency than belt-driven dynamos, owing to their lower speed, yet they possess the advantage over the direct-driven generators in requiring a far less floor space. Moreover, they are much quieter during their operation than the belt-driven machines. Besides, they not only ensure a saving in the friction losses that occur in the belting at the counter-shaft

Necessity for ventilation of armature core.

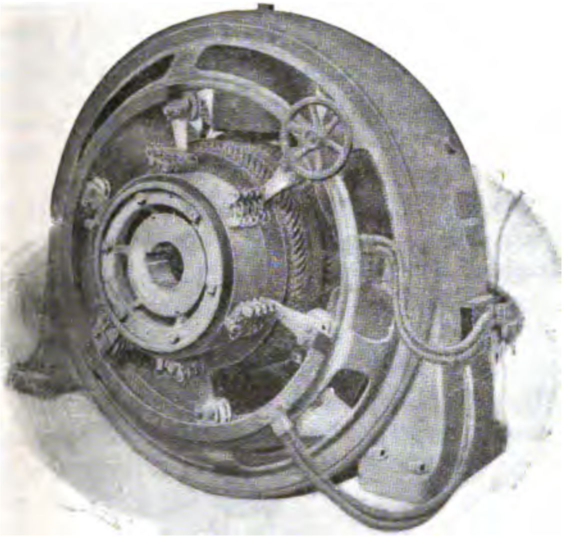


Fig. 28.—Armature and Field of General Electric Company's Direct-driven Dynamo.

Direct-driven quieter than belt-driven dynamos.

of the belt-driven machines, but also ensure a smaller wear and tear of the machines.

Another General Electric direct-driven dynamo, of the same type as the preceding, but of a smaller size, is shown in Fig. 28. Here there are but six field magnet poles and six sets of carbon brushes resting on the commutator segment. A dynamo of this size is capable of producing, at 275 revolutions per minute, a current of 800 ampères, at a pressure of 125 volts. Consequently, its output is 100,000 watts, or 100 K.W.

CHAPTER III

DYNAMO TROUBLES

"The promptness and ease with which any accident or difficulty with electrical machinery may be dealt with, whether by the inspector of construction or by the operator in charge of running, will always have much to do with the success of the plant, and of those dependent upon it."—*Practical Management of Dynamos and Motors:* PROFESSORS CROCKER AND WHEELER

THE various sources of loss which occur during the running of a dynamo, and to which we have referred in the preceding chapter, take place under all circumstances. No matter how carefully the dynamo has been designed and built, no matter how carefully it is operated or run, some loss will necessarily occur either from the mechanical or magnetic frictions, before referred to, and some energy will necessarily be expended and lost to the circuit in the shape of heat generated in the conductors on the field magnets or armature, caused by the passage through them of a current against their ohmic resistance. But besides these losses, there are others that can be traced to the improper running of the machine, or to some defects or faults occasioned either by a slight disarrangement or some faulty adjustment of some of the running parts. Such troubles tend to increase rather than to decrease, and if not promptly remedied or removed, may occasion serious loss in the shape of decreased output, and even eventually result in the entire loss of the machine. It will be well, there-

Dynamo troubles.

Crocker and Wheeler on dynamo diseases

fore, to discuss in some detail a few of such troubles, together with the steps that should be taken to remove them. In discussing these troubles in dynamos, we shall follow the order both of the troubles themselves, and the way of remedying or meeting them, suggested by Drs. Crocker and Wheeler, in their book entitled "The Practical Management of Dynamos and Motors."

Sparking at commutator brushes.

During the rotation of a dynamo, a troublesome sparking sometimes occurs between the collecting brushes and the segments of the commutator, on which they rest. In the case of certain arc-light machines, where the value of the current generated is not very great, this sparking, unless pronounced, is not very objectionable; but where the currents are large, the sparking may occasion considerable damage, from the undue heating of the commutator, or even of the armature itself. Moreover, such sparking will cause serious difficulty from the irregularities produced in the surface of the commutator.

There are many different causes for sparking at the commutator. Of course, wherever such sparking is due to structural errors or faulty design, it can only be removed either by the reconstruction of the machine, or by its replacement by another. In many cases, however, excessive sparking can be readily remedied.

Sparking due to "overload" of machine.

When a dynamo is doing more work than it has been designed to do, such, for example, as when a dynamo is operating too many arc or incandescent lamps, and has, therefore, what is called an "overload" on its external circuit, the passage of too powerful a current through the armature coils may result in bad sparking. While such an overload may be safely carried for a short time, it should never be carried for extended periods of time.

Sometimes sparking is due to the collecting brushes being improperly set on the commutator segments. In order to carry off the current quietly, the ends of the brushes should rest at the neutral points, or on the diameter of commutation. If the brushes are improperly set, sparking will occur, and of course this can be remedied only by properly adjusting their position.

Sparking due to improper position of brushes.

In machines that have been run for some time, the commutator segments become rough and irregular, either from unequal wear, or from the pitting or burning of parts of the surface by excessive sparking. These irregularities cause the brushes to jump whenever they pass over them. Such sparking may be removed by carefully smoothing the surface of the commutator segments either by means of sandpaper or a file. Emery paper should never be employed for this purpose. Where the irregularity is very marked, it is sometimes advisable to remove the armature from the machine and place it in a lathe, where its surface can be trued by the proper use of a cutting tool. In all such cases care must be taken to carefully remove all the metallic dust formed by cutting or filing, since this might afterward form a short circuit between adjacent commutator segments. A small quantity of vaseline or oil may be used to decrease the friction between the brushes and the commutator segments. An excess of either lubricant will, however, be apt to produce trouble, by preventing the brushes from forming a good electric contact with the commutator segments.

Sparking due to irregularities in commutator surface.

Use of lubricant on commutator.

Sparking due to imperfect brush contact.

Sparking is frequently caused by the collecting brushes making a poor contact with the commutator segments. Instead of touching evenly over all portions of their ends, they only make contact at a corner. This may arise either from lack of sufficient pressure, or it may come from the presence of dirt or too much oil on the commutator segments. The remedy for either of these difficulties is evident.

Sparking due to change in diameter of commutator.

Any cause which tends to change the position of the diameter of commutation on the machine will necessarily produce sparking at the commutator. For example, if, owing to an accident, one or more of the armature coils become short circuited; or if the direction of current in such coils is reversed; or if the circuit of one or more such coils becomes broken, the symmetrical distribution of E.M.F.'s and current in the armature is disturbed, and a shifting of the diameter of commutation results. In such cases the only remedy is to replace or properly connect the faulty coils. Their presence is generally indicated by the excessive temperature they will be found to have on the stopping of the machine.

Sparking due to insufficient field flux.

The position of the diameter of commutation may also be shifted by some disarrangement occurring in the field magnets, by means of which the supply of magnetic flux is diminished. This difficulty is apt to occur in shunt-wound machines, and may be caused either by poor contacts, or through excessive resistance introduced into the circuit of the field magnets. We will inquire briefly, therefore, as to the difference between series-wound, shunt-wound, and compound-wound machines.

In series-wound machines the field magnet coils and the external circuit are so connected in series

Series-wound dynamos.

Regulators for series-wound dynamos.

with the armature circuit that the entire armature current passes through the field-magnet coils. In other words, the field circuit and the external circuit are connected in series with the armature circuit. Under these circumstances, any increase in the resistance of the external circuit will cause a decrease in the E.M.F.'s generated by the machine, on account of the decrease in the amount of magnetic flux which passes through the armature coils. On the other hand, any decrease in the resistance of the external circuit will be attended by an increase in the E.M.F.'s, by reason of the increased magnetic flux passing through the armature. In series-wound dynamos, the variations produced in this way by differences in the load placed on the machine are avoided by the use of a variety of apparatus called regulators, the action of which will be explained under the head of electric lighting. The connections of the supply main of a series-wound generator with the surface of the armature and the field magnet coils are shown in Fig. 29. Since series-wound machines, when employed in connection with a regulator, tend to maintain a constant-current strength in their circuit, they are sometimes

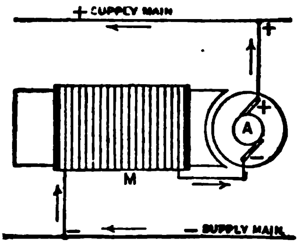


Fig. 29.—Series-wound Dynamo. Note the connection of the positive brush to the positive supply main, and the connection of the negative brush to one end of the field magnet coil M, the other end of this coil being connected with the negative supply main.

called constant-current machines. Their use is principally for furnishing current for series-connected arc lamps.

In shunt-wound dynamos, as shown in Fig. 30, the field magnet coils are placed in shunt with the armature circuit, so that only a portion of the current generated in the armature coils passes through the coils of the field magnets; but all the difference of potential generated in the armature acts at the terminals of the field circuit. In shunt-wound machines, the field magnet coils consist of a great number of turns of very fine wire, so that their resistance is much greater than that of the armature coils. This difference may vary from 400 to 1,000 times that of the armature resistance.

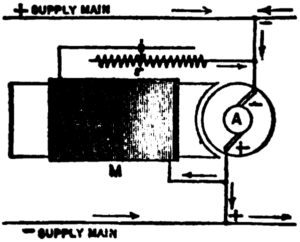


FIG. 30.—Shunt-wound Dynamo. Note the connection of the field magnet coil M in shunt with the armature coils, and the connection of the armature to the supply mains. A part only of the current of the armature passes through the field-magnet coil.

Definition of shunt-circuit.

A shunt circuit consists of a branch or additional circuit, placed at any part of a circuit through which the current branches or divides, a part flowing through the original circuit, and the remainder flowing through the branch or shunt circuit. Suppose, for example, the current from the two voltaic cells, represented in Fig. 31, be provided with two separate circuits at *r* and *r'*, so that the current may branch or divide at A, and reunite again at B, after having passed through *r* and *r'*. Then either of these branches, *r* and *r'*, may be regarded as a shunt to the other circuit. The relative strengths of the current passing through *r* and *r'* will be inversely proportional to their resistance. For example, if the resistance of *r* be two ohms, and the resistance of *r'* be three ohms, then three-fifths of the whole current strength will flow through *r*, and the remaining two-fifths will flow through *r'*.

In any shunt-wound dynamo, it follows that an increase in the resistance of the external circuit will cause an increase in the E.M.F.'s of the machine, and that a decrease in such resistance will cause a decrease in the E.M.F.'s generated. These actions, it will be observed, are just the reverse of those that occur in the series-wound dynamo.

Action of shunt-wound dynamo.

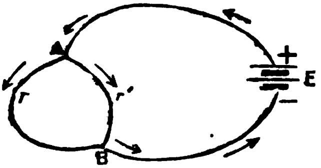


Fig. 31.—Shunt-circuit. Note the fact that the current leaving the + pole of the voltaic cell at E branches or divides at A, one part flowing through *r* and the remainder through *r'*, the two branches reuniting at B and entering the battery E, at its negative pole —.

In a shunt-wound dynamo, a continual balancing occurs, the current dividing at the brushes between the field magnets and the external circuit, in inverse proportion to the resistance of each circuit. It is for this reason that, if the resistance of the external circuit increases, a proportionally greater current will flow through the field magnets, and so cause an increase in the value of the E.M.F.'s; while, on the contrary, if the resistance of the external circuit be decreased, a smaller proportion of current passes through the field magnets, a smaller amount of magnetic flux is generated, and a smaller value of the E.M.F.'s is produced. In Fig. 30, the resistance *r* is inserted in the circuit of the shunt-wound generator, in order to control the amount of magnetic flux produced by the field magnets.

Nearly constant current produced by shunt-wound dynamo.

A shunt-wound dynamo is capable of maintaining a nearly constant current at the terminals of either series or parallel connected circuits. In parallel or multiple circuits, however, such, for example, as are required for incandescent lamps, the introduction of a considerable number of additional lamps in the circuit tends to produce a slight drop of potential. In order to avoid this, compound-wound generators are employed.

Compound-wound dynamo.

In a compound-wound dynamo or generator, as shown in Fig. 32, the field magnets of the machine are wound with both series and shunt connected coils. The shunt coils consist of a great number of turns of fine wire, while the series coils consist of a few turns of coarse wire. Remembering that the effect produced on the value of the E.M.F.'s in a series-wound generator, by either increasing or decreasing the load on the machine, is exactly in the opposite direction to the effect produced in a shunt-wound generator, it will be evident that, in compound-wound machines, the relative values of the shunt and series windings may be so proportioned that the decrease in pressure that would take place by reason of the shunt windings might be offset by the increase in pressure

Automatic regulating action of compound-wound generator.

that would take place by reason of the series windings, so that a compound-wound machine should be able to maintain a constant value of the pressure at its terminals for all variations from no load to full load.

General use of differently wound generators.

It will be interesting here to state that, generally speaking, the series-wound generators are employed for all series-connected circuits, such as are seen in series-connected arc lights, or series-connected incandescent lights. The shunt-wound generator is usually employed for central-station incandescent parallel systems, and for some motor circuits. Compound-wound generators are generally employed in street-railway systems, and in most cases of direct-current motors, as well as for isolated incandescent parallel-systems of lighting.

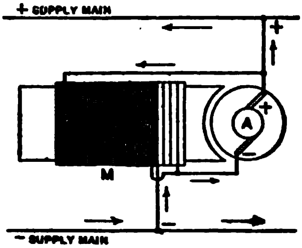


FIG. 32.—Compound-wound Dynamo. The arrows show the directions the currents generated in the armature take through the shunt and series coils and the supply mains.

Heating of dynamo.

During the operation of a dynamo or generator, an increase occurs in the temperature of the machine. Where such increase of temperature is not too great to be borne by the hand pressed against the heated part for a few minutes it need occasion no anxiety; but, if it is too painful to be thus borne by the hand, and it is, moreover, accompanied by a

Lump of ice on journal bearings.

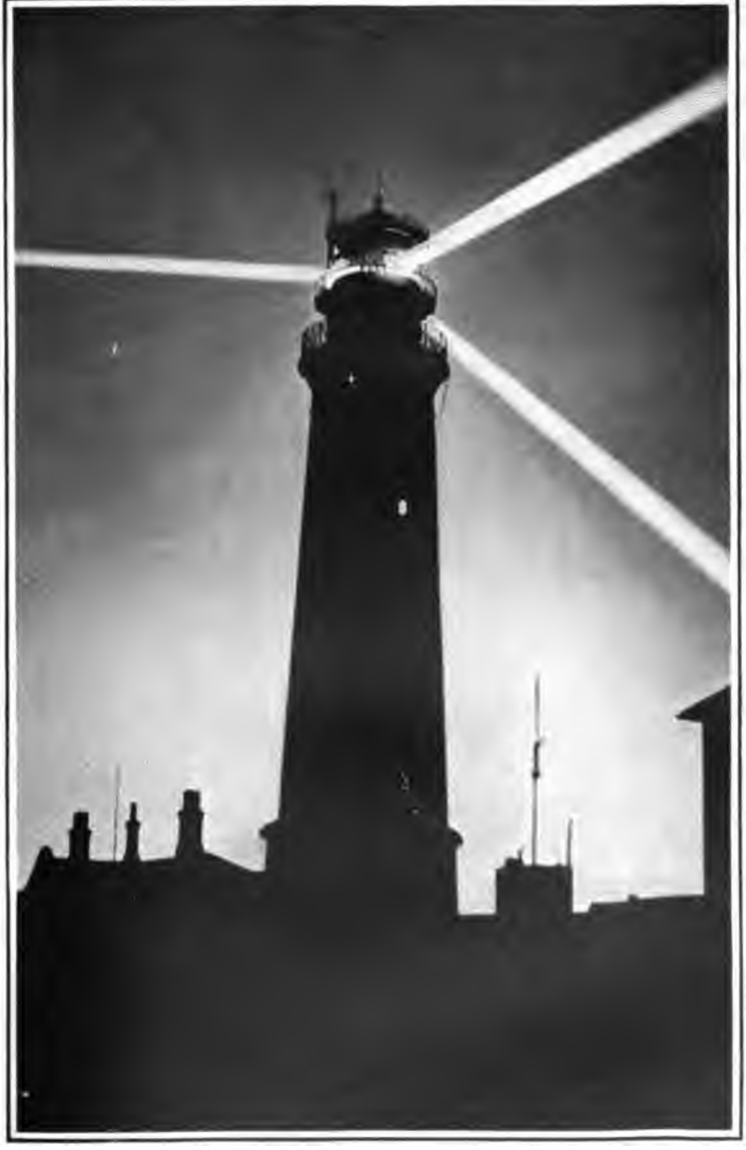
smell of burning insulation, the machine should be instantly stopped before serious damage is occasioned. Of course, the application of water is dangerous, although in the case of overheated journal bearings, where the stoppage of the dynamo would mean the extinguishment of light in a building or other space, in order to avoid the inconvenience, a lump of ice may be held against the journal bearings, care being taken to prevent any water from falling on the armature or commutator.

Temperature limits of generators.

Of course, any increase in temperature of the conductors of the field magnets or armature coils produces an increase in their resistance, and thus tends to diminish the output of the machine. Consequently, manufacturers are required to guarantee that their machines shall not increase in temperature during their running beyond certain definitely stated limits; for instance, in case of the direct-connected General Electric Company's generator, shown in Fig. 27, the company guarantees that, after a run of twenty-four hours, at the rated value of the ampères and volts for which the machine was designed, and with satisfactory conditions of ventilation, the increase in temperature shall not be greater than 95° F.; and that the temperature of the commutator shall not exceed 104° F., above that of the surrounding air; when there is an overload of say fifty per cent above the rated ampères and volts, they guarantee that after a run of two hours the accumulated temperature in all parts of the generator shall not exceed 121° F.

Where good design and construction show.

The influence of good design and construction on the amount of sparking at the commutator brushes of large generators will be noted in the case of the machine shown in Fig. 27, in which it



POWERFUL ELECTRIC LIGHT IN THE HELIGOLAND LIGHTHOUSE

The lighthouse at the mouth of the Elbe, on the island of Heligoland, has recently replaced its old kerosene lamps by a very advanced electric system, giving an illumination of 30 million candle-power. Three lamps are used, and the light has been seen 40 miles away

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is possible to carry an overload of current amounting to fully fifty per cent for two hours, or an overload of one hundred per cent momentarily, without shifting the position of the collecting brushes, and without injurious sparking.

Some sources of excessive heating in armature bearings.

The excessive generation of heat in the armature bearings and field-magnet coils may arise either from sparking at the commutator brushes, or it may be due to an overheated commutator, which has disintegrated the carbon brushes employed, and has so spread a film of high resisting material over the surface of the commutator segments. In all these cases, to the heat generated by any of these causes, is to be added the heat generated by the causes of loss referred to in the preceding chapter.

Execssive heating at the journal bearings may be due to lack of proper oiling, or it may arise from the shaft or the bearings fitting too tightly. Sometimes this heating is due to lack of proper alignment of the bearings, or it may be due to the shaft being bent accidentally. Heating will also arise from the striking of the belt against one or both of the bearings, or from too great a strain of the driving belt.

Trouble from noises.

A trouble that sometimes arises during the operation of the dynamo is that which comes from various noises produced. In many cases such noises are objectionable largely on account of the regularity with which they recur. In many cases these noises can be traced either to imperfectly constructed or insufficiently provided foundations, or from a failure to properly secure to such foundation the frame on which the dynamo rests. Where the foundation of a dynamo is placed on solid rock, the vi-

Noises due to foundations.

brations or noises produced by the machine are thereby more readily conducted into the building, where they may cause annoyance. In such cases, in order to deaden these sounds and lessen the ease with which they can be transmitted, various materials, such as sand, wood, or asphalt-concrete, have been employed.

Noises of various kinds.

Another class of noises, however, may be due to some trouble existing in the dynamo itself. For example, either the driving pulley or the armature may be unbalanced, and thus may produce periodically recurring noises. The coils on the surface of the armature may become loosened, and thus periodically strike the pole pieces. Moreover, in the case of belt-driven dynamos, which are run at high speeds, the belt during its motion may produce disagreeable sounds, or it may periodically strike against some surface. A disagreeable chattering noise is sometimes produced by the jumping or slipping of the brushes on the commutator segments.

Possible causes of insufficient speed of rotation.

During the operation of a dynamo care should be exercised to maintain the speed approximately constant. Where a slowing down of the machine is observed, if not due to a failure on the part of the driving engine or turbine to deliver the usual amount of power for driving purposes, it may be due to an overload produced in some way on the machine. This overload, calling for the expenditure of a greater amount of energy than that which the driving dynamo or turbine can supply, is necessarily followed by a decrease in the speed of rotation. Whenever it can be done without too great inconvenience, on the appearance of almost any of the troubles before referred to, the machine should be stopped, and an examination made as to the cause of the trouble; for, as has already been mentioned, dynamo troubles tend rather to increase than to decrease, so that, if the machine is permitted to continue running, a serious damage may occur.

Great value of the dynamo as an electric source.

Lack of space prevents any further discussion of this extremely important device; viz., the dynamo-electric machine. As we have already seen, the invention of the voltaic battery marked an era in the history of electric science, since, by its means, it became possible to readily produce powerful electric currents by the transformation of chemical energy into electric energy. In the same way, the invention of the dynamo marked a still greater era in such history; for the dynamo, as an electric source suitable for the cheap and ready production of powerful currents, was itself as great an advance over the voltaic battery as the voltaic battery was over the old frictional electric machine. Since the time of the production of the first dynamo by Faraday, in 1831, until the present time, very considerable improvements have been made in this apparatus. Concerning these improvements, the Author, in connection with his late colleague, Dr. A. E. Kennelly, thus speaks, in their work entitled "Recent Types of Dynamo-Electric Machinery":

Houston and Kennelly on the improvements in dynamo-electric machinery.

"During the last decade rapid strides have been made both in the number and size of dynamo-electric machines. Thus, in 1890, the largest dynamo-electric machine constructed in the United States was of about 500 horse-power, while at the World's Columbian Fair, in 1893, a 2,000 horse-power dynamo was exhibited, which was justly regarded as of colossal proportions. And yet, only three years later, a 5,000 horse-power dynamo was constructed and set to work at Niagara Falls. Although this is by no means the limit to the possible power of the dynamo-electric machine, yet it is the greatest power which has, up to the present time, been placed in a single dynamo in actual use.

Improvement in mechanical and electrical qualities.

"Coincident with this development in size, there has also been a development in mechanical and electrical qualities. The dynamo-electric machines of past years were often mechanically frail. The wires carried upon the revolving armatures were liable to accidental derangement. The dynamo-electric machine of the modern type is not only much stronger than its predecessor in mechanical qualities, in self-lubricating capability, and in durability, but is also more efficient electrically. Large dynamos, when free of journal friction, claim an efficiency of ninety-seven per cent: or, deliver as electrical power, at full load, ninety-seven per cent of the power expended in driving them, thus losing only about three per cent in the process.

"Development in dynamo-electric machinery has followed definite and well recognized lines. While it is impossible to predict what the dynamo-electric machine will be in the middle of the next century, yet we may be satisfied that its development will, probably, go forward from the present time along the direction which it has followed in the past five years.

Special types of dynamos and motors for special kinds of work.

"It has only been during the last ten years that special types of dynamos and motors have been designed for special kinds of work. This is especially true in the application of motors. Prior to this time, motors were practically applied alike to all classes of work, independently of the particular service they were required to perform. At the present time, both dynamos and motors are constructed of types suited for each particular class of work. Thus, the type of dynamo suitable for supplying current to an office building differs from the type suitable for supplying power to a long distance. The travelling motor, such as applied to a crane, or a street-car, differs from the stationary motor intended to operate a line of shafting."

Subsequent improvements.

The above book was published only toward the close of 1897 (December, 1897). In the short interval between 1897 and the date of publication of the present book (1903) the size of dynamo-electric machines has been doubled, for generators of 10,000 horse-power output have been designed, and are now being constructed for utilizing the power of Niagara Falls, in a generating plant located on the Canadian side.

Reaction principle of some dynamos.

When the armature of either a series or a shunt-wound machine begins to rotate, the values of the E.M.F.'s generated in the armature coils are very small, on account of the magnetic flux passing through the armature being limited to the residual magnetism in the field magnet cores and pole pieces. Soon, however, the currents produced by the armature being caused by the commutator to flow in one and the same direction, pass through the field magnet coils, and, increasing the amount of magnetic flux passing through the armature, cause an increase in the E.M.F.'s generated in the armature coils. This, again passing through the field magnet coils, causes a still higher E.M.F. to be generated in the armature. This reaction existing between the armature and the field magnets goes on until soon the dynamo is giving its full output. This process, called the "building-up" of the machine, or, more generally, "the reaction principle of the dynamo," was discovered by Soren Hjorth, of Copenhagen, in 1855.

CHAPTER IV

ALTERNATING ELECTRIC CURRENTS

> "In alternate-current working the current is rapidly reversed, rising and falling in a succession of pulses or waves. Electricity is in fact oscillating backward and forward through the line with enormous rapidity, under the influence of a rapidly-reversing electromotive-force."—*Dynamo-Electric Machinery:* THOMPSON

Definition of alternating electric currents and E.M.F.'s.

ALTERNATING electric currents are those which alternately change or reverse the direction in which they flow, flowing for a certain time in one direction, and then reversing this direction of flow, and continuing for an equal length of time in the opposite direction. These changes in the direction of the current are repeated or follow each other at regular intervals. The fact that the direction of flow thus alternates or changes has given to these currents the name of alternating electric currents. Since, as in all currents, the flow is produced by the action of E.M.F.'s, the E.M.F.'s necessary to produce alternating electric currents must necessarily be alternating E.M.F.'s.

Definition of continuous electric currents.

A continuous current is a current which does not change the direction of its flow, but continues in one and the same direction during all the time that the current continues. Unless otherwise stated, all continuous currents preserve the same current strength during all the time they are flowing. As already explained, the current strength is constant only after such currents have attained their full current strength. Both at the moment of closing and opening a continuous current circuit, a change occurs in the strength of the current.

Each change or reversal in direction of an alternating current is called an alternation. If a certain dynamo or machine is producing four hundred alternations per second, it reverses its direction four hundred times in each second, producing two hundred waves of current in one direction, and two hundred waves of current in the opposite direction during each second of its flow. Each double reversal or complete to-and-fro motion is called a cycle. The number of cycles per second is called the frequency. Consequently, the preceding machine will be said to possess a frequency of two hundred cycles per second, or, as it is generally written, 200 $\sim$ per second. The symbol $\sim$ stands for cycles. The time required to produce one complete cycle is called a period. If a machine produces one complete cycle in a period of $\frac{1}{200}$ of a second, it must produce two hundred cycles in each second, and its frequency must be 200 $\sim$.

Alternation

Definition of cycle and period.

Symbol for cycle.

Continuous or alternating electric currents, so far as the direction of their flow is concerned, resemble the flow of water in a river. In all rivers that discharge directly into the ocean, in those parts of their course too far above the river's mouth to be affected by the tides, the water flows constantly toward the river's mouth; or, in other words, the flow is limited to a single direction, like that of a continuous electric current. In regions near the river's mouth, however, where the water is affected by the tides, the direction of the flow of the water alternates or changes about four times in every twenty-four hours. The water flows up-stream for about six

Analogue of continuous and alternating currents to flow in tidal rivers.

hours, and then reverses, and flows down-stream, or toward the river's mouth, for an equal period of time, these motions being again repeated during each twenty-four hours. Here, however, there is a great difference in the number of alternations, the river possessing practically only four alternations per day, and, consequently, having a frequency of so small a number as only two complete alternations, or two complete cycles for every twenty-four hours, while, in the case of alternating currents, there may be several hundred cycles per second.

The alternate to-and-fro motions of water in a tidal river can be graphically represented as follows.

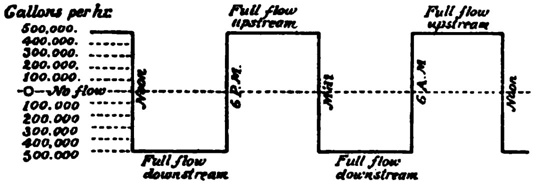


FIG. 33.—Curve representing tidal flow of water in river. Note the position of the horizontal line of zero or no flow.

Curve of tidal flow in river.

Here a horizontal line is divided into equal lengths representing the time corresponding to noon, six P.M., midnight, six A.M., and noon, as shown in Fig. 33. A vertical line drawn at the extreme left of the horizontal line, extending both above and below the horizontal line, represents respectively the flow up and down stream. Here the numbers from 100,000 to 500,000 represent the volume or amount of the flow in these different directions. Then, in the case of a tidal river, the irregular curve represented in the figure gives the value of the flow up and down stream respectively. An examination of the figure will show that between noon and six P.M., nearly

500,000 gallons of water per hour, or, approximately, 140 gallons per second, flow steadily downstream toward the river's mouth, and that the same quantity flows up-steam from six P.M. to midnight.

Curve showing alternating current flow in alternating-current circuit.

In a similar manner we can represent the flow of alternating electric currents. Here let us suppose that the alternating current has a frequency of one hundred cycles, or two hundred alternations per second, and that the strength of such current is fifty coulombs per second in one direction, and fifty coulombs per second in the opposite direction. Then, letting the horizontal line represent the times and the vertical line the current strength, the curve shown in Fig. 34 would graphically represent such alternating electric currents. Here fifty coulombs of electricity per second would flow through the circuit in one direction, and fifty coulombs per second in the opposite direction. But, since a coulomb-per-second is equal to one ampère, we can represent the flow as being equal to a flow of fifty ampères in one direction, and fifty ampères in the opposite direction.

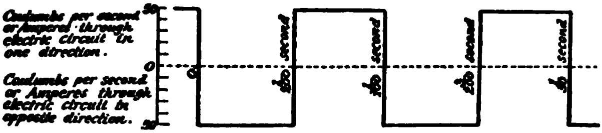


FIG. 34.—Curve representing alternating flow of electricity in alternating-current circuit. Note the resemblances between this curve and that represented in Fig. 33.

Direction of alternating current flow in conducting loop rotated in bipolar field.

Since, as we have seen, the direction of current flow in a conducting loop rotated in a bipolar field changes or reverses during each rotation, all currents so produced are necessarily alternating currents. For example, a coil of wire being rotated on a horizontal axis between two magnetic poles N and

S, Fig. 35, and the ends of such coil being connected as shown to the two metallic rings mounted on the axis, the coil being rotated so as to cause the upper portion to come toward the observer, then the current produced during one-half rotation would have the direction indicated by the arrows. At the moment the coil reaches the position shown in the figure, the current flows to the left-hand ring, and, after having passed through the external circuit connected with this ring, returns to the coil by way of the right-hand ring. After a half turn, however, the direction of the current generated would be reversed: *i.e.*, it would then flow through the right-hand ring to the external circuit, and, after having passed through that circuit, would return to the coil by the left-hand ring.

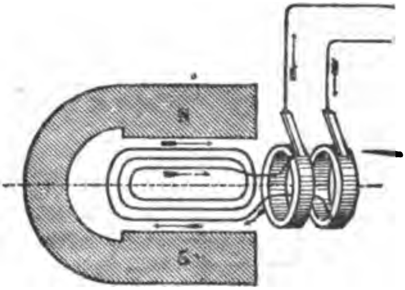


Fig. 35.—Simple Alternating-current Generator or Magneto Ringer. Note the fact that the collecting rings are continuous, so that the collecting brushes must change in polarity twice during each rotation of the coil.

Magneto-electric generator.

The device shown in the above figure constitutes an early form of magneto-electric generator for producing alternating currents, and was employed for the purpose of ringing bells. By suitably connecting the ends of the coil to a two-part commutator the machine is capable of producing continuous electric currents.

Magneto-electric generators of Pixie, Saxton, Clarke, and Ritchie.

Shortly after the announcement of Faraday's discovery of electro-dynamic induction, a variety of magneto-electric machines were produced, among others, by Pixie, Saxton, Clarke, and Ritchie. One of the best-known forms of these machines was that devised by Clarke, and is seen in Fig. 36. Here the armature coil consisted of two separate coils wound on soft iron cores, and containing some 1,500 turns of copper wire in each coil. The coils were suitably connected, so as to form a single coil, and were rotated before the two poles of a compound horseshoe magnet. The ends of the coil were connected to a two-part commutator, and the commuted currents were passed through the collecting brushes.

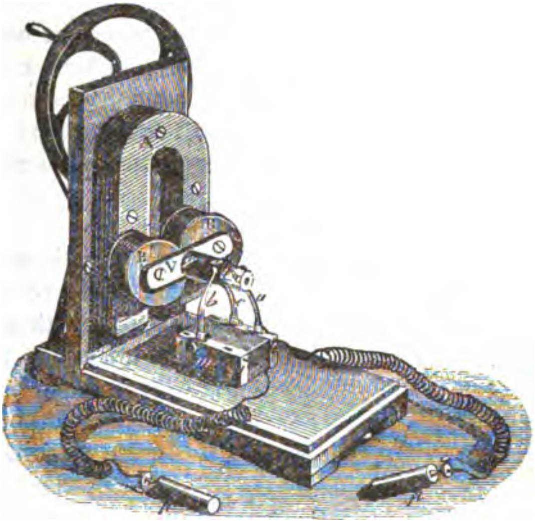


FIG. 36.—Clarke's Magneto-electric Generator.

When a person grasped these handles the currents were sent through his body.

Effect of self-induction and capacity in alternating-current circuits.

In a continuous-current circuit the strength of current flowing under the influence of a given E.M.F. depends only on the value of the ohmic resistance. In an alternating-current circuit, however, besides the ohmic resistance, there are two other quantities that oppose such flow, and, therefore, together with the ohmic resistance, must be considered in determining the value of the current strength. These two additional quantities are the inductance or self-induction, and the capacity, that may be placed directly in or connected with the circuit.

Reactance.

When, for example, an alternating electric current is passed through a coil of wire consisting of many turns, especially if such coil be provided with a soft iron core, there is an influence set up which tends to choke or oppose the passage of the current. This influence is called the reactance, and is due both to the self-induction or inductance of the circuit, and its capacity.

Spurious or apparent resistance of alternating electric circuit.

During the passage of an alternating electric current through a coil provided with a soft iron core, the expanding and contracting lines of magnetic force, cutting or passing through the loops of the conductor, set up therein E.M.F.'s and currents by means of electro-dynamic induction. These induced E.M.F.'s or currents offer an additional resistance, sometimes called the spurious resistance, to the passage of the current; or, in other words, there is produced a reactance or additional resistance set up in this way by the action of self-induction or inductance. At the same time there is an additional reactance set up due to the capacity of the conductor in a manner that we shall shortly explain. The additional opposition thus introduced into the circuit through reactance produces a marked change in the value of the total apparent resistance of the circuit, or, as it is called, in the impedance of the circuit. Here the word impedance can be taken as signifying generally an opposition to current flow. Its value depends on the value of the ohmic resistance of the conductor and the spurious resistance of the conductor measured in ohms.

Impedance of alternating electric circuit.

The total effective resistance in such cases can not be determined by merely adding together the ohmic resistance and the reactance. Suppose, for example, that in a given case the resistance of an alternating current circuit were three ohms, and the reactance in such circuit four ohms, the frequency of the circuit being fifty cycles per second. Then the total effective resistance would not be equal to seven ohms, but must be calculated by drawing a line, whose base shall represent the value of the ohmic resistance, and a perpendicular line at one end of such a base, whose length shall represent the reactance. Then the combined influence of the resistance and the reactance, or the effective resistance, will be represented by the length of the hypothenuse, or will be five ohms. Remembering now that a portion of the impedance in an alternating-current circuit is due to the inductance, or self-induction of the circuit on itself, it is clear that the value of the impedance in an alternating electric current circuit must increase both with the increase in the frequency of the circuit, and with the number of turns or loops of wire on the coil. Moreover, it is also clear that the induction of a soft iron core must tend markedly to increase the value of the impedance,

Total effective resistance of alternating electric circuit.

Impedance, how affected.

from the increased value of the inductance thus occasioned.

Reactance caused by introduction of condenser in circuit.

When the terminals of a condenser C, Fig. 37, are connected in an alternating-current circuit C, D, B, there will occur a continued charging and discharging of the condenser. Consequently, currents will flow into the alternating-current circuit, despite the fact that the opposite ends of the condenser are insulated from each other by an air space which offers an extremely high ohmic resistance. The condenser circuit is, in this sense, equivalent to a closed circuit having an apparent resistance, the reactance of which can be represented in ohms. Here, clearly, the flow of current increases directly with the capacity and frequency. Consequently, the reactance must be inversely proportional to the frequency and the capacity. In other words, while the impedance of an alternating electric circuit due to inductance increases with the frequency, the impedance due to capacity decreases with the frequency. Consequently, self-induction or inductance and capacity can be made to neutralize or counteract each other, that is, the reactance due to induction can be made to balance the reactance due to capacity.

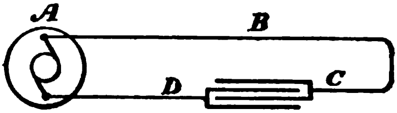


Fig. 37.—Effect of condenser on impedance of alternating electric current.

The practical unit of inductance is called the henry, after Prof. Henry, the American electrician already referred to, and is equal to the inductance of a circuit when the E.M.F. induced in it is equal to one volt, while the inducing current varies at the rate of one ampère per second. In other words, if a counter or opposing E.M.F. of one volt is set up in the coil by the action of self-induction, when the current is increased at the rate of one ampère per second, then its self-induction is equal to one henry.

The henry or practical unit of inductance.

The power possessed by coils of wire of many turns, when provided with a core of soft iron, to cut off or choke alternating electric currents, has caused the name of choking coils to be given to them. Choking coils are employed in a great variety of electric apparatus for automatically choking or stopping the passage of electric currents without loss of energy. In a continuous-current circuit the amount of current passing can be choked or limited by the introduction of mere ohmic resistance. Here there is necessarily a useless expenditure of energy, for the E.M.F. continues to act on the extra resistance. When, however, a choking coil is introduced into an alternating-current circuit, the opposing E.M.F.'s produced by self-induction prevent the E.M.F.'s which are endeavoring to force current through the coil from acting. Consequently, there is no loss of energy.

Choking coils.

Where it is desired to reduce the impedance of the circuit the area of the conducting loops is made as small as possible by placing the leading and returning circuits as near together as possible, that is, by placing the two halves of the circuit through which the current leaves and returns respectively to the source, near together, thus decreasing the area of the loops through which the magnetic flux can pass. This is sometimes done by the use of concentric tubular conductors, where one of the conductors forms

How the value of the impedance may be decreased.

one lead and the other conductor the returning lead. When either the lead or the returning conductor, carrying an alternating current, is placed inside an iron pipe, considerable increase in impedance will occur, from the magnetic flux set up in the surrounding mass of iron. If, however, both the lead and the return are placed inside the same iron pipe, no bad effects are produced.

Use of concentric tubular conductors.

Since the impedance, or the apparent resistance of an alternating-current circuit, differs so greatly from the ohmic resistance, Ohm's law for determining the value of the current strength in such circuits can not be directly employed. Suppose, for example, that a given electric circuit, in the shape of a coil, has an ohmic resistance of one-fifth of an ohm, and that a continuous E.M.F. of one volt be maintained between the ends of its terminals; then the current passing would, as determined by Ohm's law, be equal to one volt divided by one-fifth of an ohm, or five ampères; but, if an alternating E.M.F. of one volt, at a frequency of one hundred and twenty-five cycles, or two hundred and fifty alternations per second, be applied to the terminals of the coil, then the current strength would be considerably reduced, and might be only two ampères instead of five ampères, in the case of the continuous current.

Why Ohm's law needs modification for alternating-current circuits.

When rapidly alternating currents are passed through a solid conductor, the current possesses a much greater density in portions of the conductor which lie near its surface than in those near its centre or axis. Indeed, if the frequency of the currents be high, the central parts of the conductor may be completely free from any current. Since the total area of cross-section of the conductor is not utilized

Skin effects of alternating electrical currents for the passage of such currents, the resistance of the conductor is thus virtually increased. For this reason, this increased resistance is sometimes called the virtual resistance of the conductor. This effect is known as the skin effect. It is on account of the skin effect that the oscillating or rapidly alternating currents produced by disruptive lightning discharges pass better through stranded conductors than through solid conductors of equal area of cross-section.

The insulating medium surrounding a conductor the real path of its current.

The fact that very rapidly alternating currents are limited to the surface of conductors would seem to lend great probability to the modern theory that an electric current is not transmitted through the substance or mass of the conductor, but rather through the non-conducting medium which lies outside the conductor. In a paper entitled "The Insulating Medium Surrounding a Conductor, the Real Path of Its Current," by Houston and Kennelly, the authors, referring to the generally entertained belief that electric currents are transmitted as electric waves through the ether surrounding the conductors being guided by the conductor in this transmission, speak as follows:

Houston and Kennelly on the real path of electric currents.

"Both electric and magnetic fluxes contain energy. Work must be charged on the flux to establish it, and this work is liberated when the flux disappears. The energy in the ether varies as the square of the flux density, so that if we crowd uniformly twice as much flux through a given area of cross-section, we quadruple the amount of energy which resides in that portion of space per cubic inch, or per cubic centimetre.

"The electric transmission of power consists in transferring electric and magnetic flux to a distance and allowing these fluxes to be expended in liberating, at the receiving end of the line, the energy they contain. An electric generator is a machine for producing electric flux and thus transferring electric energy to the ether. This electric flux, or energized condition of the ether, is transferred to a distant point along wires, the ether being deprived of its energy at the receiving end of the line. The electric flux is there absorbed, and the work which was expended by the generator is recovered to a greater or less extent.

"The electric flux is transmitted from the generator to the receiver, through an insulating medium, being guided on its passage by a pair of conductors, extending all the way from the generator to the receiver. Such a pair of conductors, with the associated insulating medium between them, is called an electric circuit. The curious fact exists that while the old conception of an electric circuit held that the electric current passed through the conductors, and was retained in position on those conductors by reason of the insulating medium surrounding them, the modern view holds, on the contrary, that the electric current flows through the insulating medium and is held in position, or guided to its destination, by the two conductors. In other words, the modern theory completely reverses the relative functions of the insulator and conductors in the old theory."

Lag and lead of current as regards the E.M.F.

The reactance of a conductor does not only serve to oppose the passage of the current by the introduction of additional resistance, but it also causes such current to lag behind the E.M.F. that produces it. In the same way the inductance produced by the capacity of the conductor causes a lead in the current. In a continuous-current circuit, the electric activity or power is obtained by multiplying the E.M.F.

in volts by the current strength in ampères, thus giving the volt-ampères, or the watts. It is not possible to determine the power of an alternating-current circuit in this way. Should we thus multiply together the volts and the ampères, we would obtain a value for the watts that, in many cases, would be greatly in excess of the real value. What we obtain is a quantity called the apparent watts, and not the true watts. Whenever the lag or the lead of the current, due respectively to the inductance, or the capacity of the circuit, causes the E.M.F. to be out of step, or out of phase, with the current, the product of the volts by the ampères will give a value for the watts, that is in excess of the true value. This excess produces a quantity sometimes called the "wattless watts."

Apparent watts.

Another way of explaining why the apparent watts in an alternating-current circuit are in excess of the true watts, is as follows: In a direct-current circuit the E.M.F. is always acting so as to cause the current to flow in the direction in which it is already moving, while in an alternating-current circuit the E.M.F. is sometimes aiding the current and sometimes opposing it. Consequently, the product of the volts by the ampères will give a number of watts that are in excess of the true activity. The amount of this excess will, of course, depend on the length of time during which the E.M.F. is opposing the current instead of driving it through the circuit. The true activity can be obtained by multiplying the apparent activity by a quantity called the power factor, or the ratio of the real power of an alternating-current circuit to its apparent power. The value of the power factor depends upon the difference of phase between the current and the pressure. The waves of current and pressure are in step, or in phase, with one an-

Why the apparent watts of an alternating-current circuit are in excess of its true activity.

Power factor of alternating-current circuit.

other, when they are similarly directed. Otherwise they are out of step, or differ in phase.

Inductionless circuits

The power factor can never have a value greater than unity or one hundred per cent. In inductanceless circuits, or circuits containing practically no inductance, such, for example, as a circuit containing incandescent lamps, and which is practically devoid of conducting loops, the true activity may be almost equal to the apparent activity, or the power factor may have a value of nearly unity or one hundred per cent. In such a circuit current waves through the lamp filaments are exactly in step with the pressure at the lamp terminals.

Power factor of induction motor circuits under light loads.

In alternating-current circuits containing induction motors that are being operated under light load, the power factor may be as low as fifty per cent, in which case the current strength that must be supplied to the motors in order to operate them must be twice as great as would be necessary to operate them where the waves of current and E.M.F. are in step with each other.

The great advantage of alternating-current circuits.

The great advantage obtained by the use of alternating electric currents, instead of direct currents, consists in the fact that the value of the voltage can be readily changed by the use of transformers. In this way, where it is necessary to transmit a current through a great distance, the current can be employed at a high E.M.F., so that the cross-section of the conductors can be greatly decreased. Its E.M.F. can be transmitted through a long conducting line, and changed at the distant end of the line to the pressure that it is desired to employ. Where the voltage at the end of the line is doubled, the wire need only have one-fourth the area of cross-section that would otherwise be required.

If, instead of placing single coils on the armature of an alternating-current machine, two separate sets of coils be employed, one of which is placed a little ahead of the other, and we connect the terminals of these two separate sets of coils to two separate sets of collecting rings, it is evident that we will obtain, in the separate circuits connected with the collecting rings, alternating currents of equal frequency and strength, but differing from one another in phase to the extent of their displacement on the armature. Alternating electric currents obtained in this way are called multiphase or polyphase, in order to distinguish them from the single alternating currents we have already described, and which are called uniphase alternating electric currents.

Multiphase or polyphase alternating electric currents.

Multiphase currents are of two classes; viz. diphase and triphase currents. Diphase currents consist of two uniphase currents of equal strength and frequency, but differing from one another in phase by one-fourth of a period, that is, two uniphase currents that are in quadrature with each other. Triphase alternating currents consist of three separate uniphase currents of equal strength and frequency, but differing from one another by one-third of a period. Multiphase electric currents are employed for the driving of alternating-current motors, as will be more fully described elsewhere.

Diphase and triphase alternating electric currents.

Use of multiphase or polyphase currents.

CHAPTER V

ALTERNATING-CURRENT GENERATORS

> "The recent electrical development in Greater New York demonstrates this on a magnificent scale. A generation ago it would have defied the imagination to discover any natural connection between such widely different agents as horses pulling street cars, locomotives drawing elevated trains, gas lighting houses and streets, water operating elevators, stoves heating and cooking, and engines of every sort and class doing a hundred kinds of work. But all of these and many others are in common being superseded by the electric current, which does not merely replace but develops, expands and transforms. It is notable that all of this varied service is to be supplied from alternating-current generators."—CHARLES F. SCOTT, 1901

Alternating-current generators or alternators.

THE electric currents generated in the armature of a dynamo-electric machine are alternating. In a constant-current machine these alternating currents are caused to flow in the same direction by the use of commutators. In an alternator, however, they are permitted to flow through the external circuit in alternate directions. In general, therefore, an alternating-current generator, or, as it is more frequently called, an alternator, has no commutator, the current being taken directly from the armature by means of collecting rings, as shown in Fig. 35.

The frequencies generally employed vary from 25 to 140~(or cycles); from 25 to 60~being regarded as low frequencies, and from 60 to 140~ as high frequencies.

Number of alternator poles; how determined

The number of poles will necessarily depend on the speed at which the machine is driven, and on the frequency it is desired the alternating currents shall possess. As soon as these two numbers are determined the number of poles will be fixed. In all cases the field poles are alternately north and south around the field-magnet frame. Consequently, the number of poles must always be even.

Advantages and disadvantages of high frequencies.

The advantage of high frequencies in alternating-current generators lies in the fact that the size and cost of a transformer are less with high than with low frequencies. On the other hand, when the frequencies are high, where direct-connected alternators are employed, running at a speed of 100 revolutions per minute, the number of poles necessary becomes excessive. Again, another objection to high frequencies is that the value of the inductance and capacity effects are greater than with low frequencies. Moreover, with high frequencies it is more difficult to connect several alternators in parallel. As we will see, in the study of incandescent and arc lighting, it is difficult to obtain the necessary steadiness of the light with the use of frequencies of less than forty cycles for arc lamps and twenty-five cycles for incandescent lamps.

Various types of armatures for alternators.

The armature of an alternator may be either of of the ring, drum, pole, or disk type. The arrangement of the wires or conductors, however, is different from continuous-current machines. Since the fields of alternators are practically always multipolar, an armature winding that passes a north pole will have currents developed in it that will flow in the opposite direction when such winding passes the south pole. Therefore, it is necessary either to wind alternate coils in opposite directions, or to so connect them that they shall be alternately right and left-handed windings.

Two types of armature winding.

Take, for example, the alternator shown in Fig. 38, where the armature coils seen at the top of the figure are wound in alternately opposite directions, while in that shown at the bottom of the figure, they are wound in the same direction, but connected so as to be alternately right and left-handed.

Sometimes it is more convenient to rotate the field-magnet poles than to rotate the armature, as is the case in the Gramme alternator of Fig. 39, where the eight field-magnet poles are placed within a ring armature. Here the number of coils wound on the armature is four times as great as the number of field-magnet poles. Consequently, as the four separate windings pass the poles, alternating currents are produced in them differing in phase by 45°.

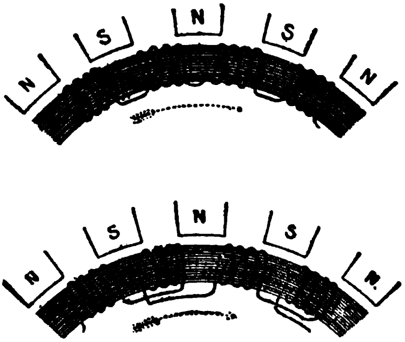
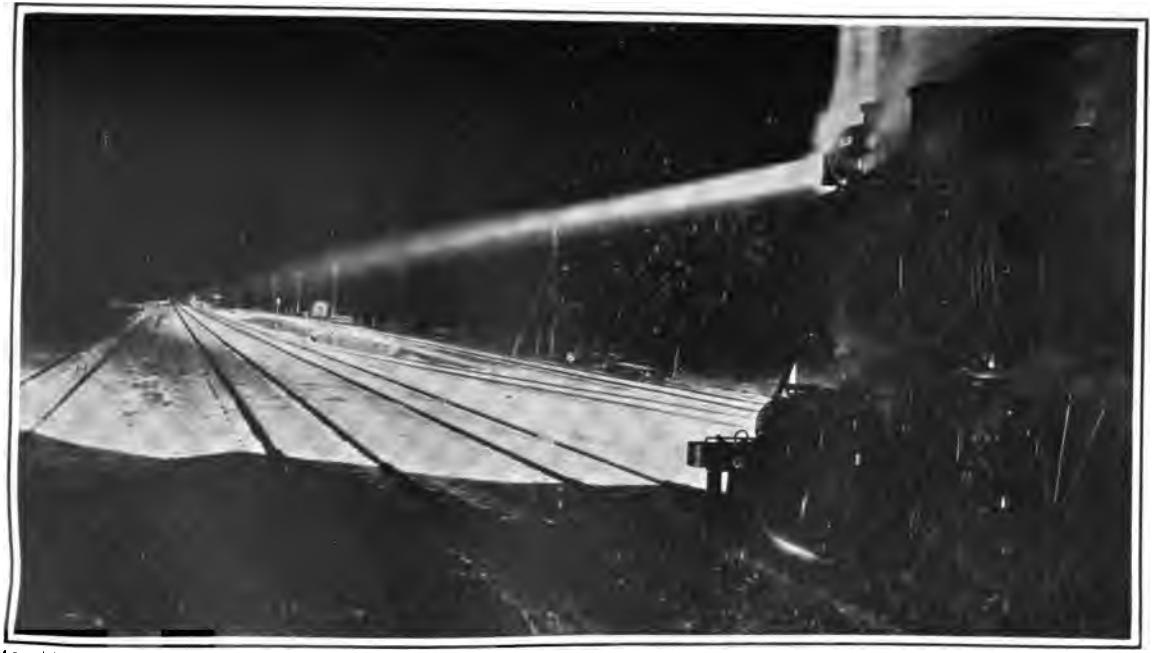


Fig. 38.—Two different types of ring-armature windings for alternators.

Early form of Gramme alternator.

In disk armatures the coils are secured to the surface of a thin disk, and are rotated between sets



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ELECTRIC HEADLIGHT ON A LOCOMOTIVE

Power is furnished for the headlight, and also for electric lights throughout the train, by a dynamo and small steam engine in the baggage car. Another train-lighting system rotates the dynamo, through gearing, from the axle of the car

of opposite field magnets S, N; N, S; S, N; etc., as in Fig. 40. Here, as will be seen, the polarity of

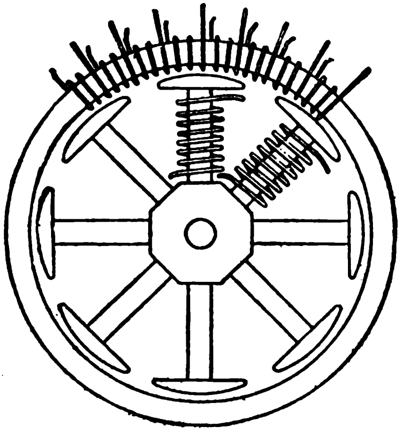

FIG. 39.—Winding of Gramme-ring Armature with revolving field magnet poles.

the field magnets alternates, but opposite poles always face each other. In this case the armature coils are without iron cores. The connection of the

Arrangement of armature coils in disk armatures.

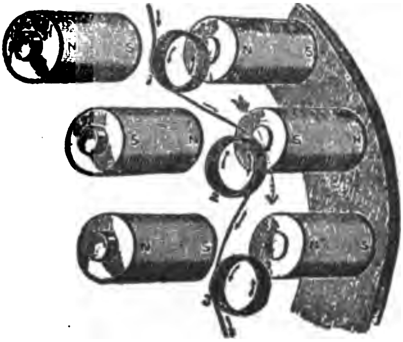

FIG. 40.—Winding of coils in disk armature of alternator.

separate armature coils to each other and to the two collecting rings is shown in Fig. 41. Here the

Series and parallel connection of armature coils.

arrows indicate the direction of the currents induced in each coil. The connection of the coils in series, and their connections to the two collecting rings, will also be seen. Sometimes, where comparatively low pressures are desired, the separate armature coils are connected in parallel, instead of in series. Owing to the rapid reversals in the direction of the current the cores of the armatures of alternators must be carefully laminated.

Compound-wound alternators.

In compound-wound alternators, as in compound-wound direct-current machines, there are two separate sets of magnetizing coils on the field-magnet cores. The current supplied to one of these coils is obtained from a separate direct-current machine, called the exciter. The current required for the other field-magnet coil is obtained by connecting a part of the armature coils to a commutator mounted on the same shaft as the collecting rings. This arrangement is seen in Fig. 42, where one of the two separate windings of the field-magnet coils is permanently connected to the small continuous-current machine which supplies the current necessary to generate the initial E.M.F., while the second winding is connected to the armature, through a shunt around the commutator. In this way only

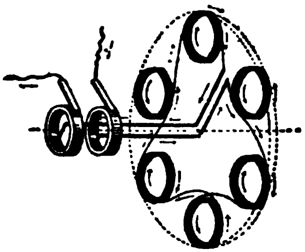

FIG. 41.—Connection of coils of disk armature of alternator.

Some details of compound-wound alternators.

some of the armature coils are commuted, and the commuted current passes through one of the windings of the field-magnet coils. This commutator is seen in the figure at C. The collecting rings are shown at L, L′. A is the main driving pulley, and P′ the pulley employed for driving the small continuous-current exciter.

Belt and direct-driven alternators

Alternators, like direct-current dynamos, are either belt-driven or direct-driven. Large sizes are nearly always direct-driven, just as in the case of continuous-current generators.

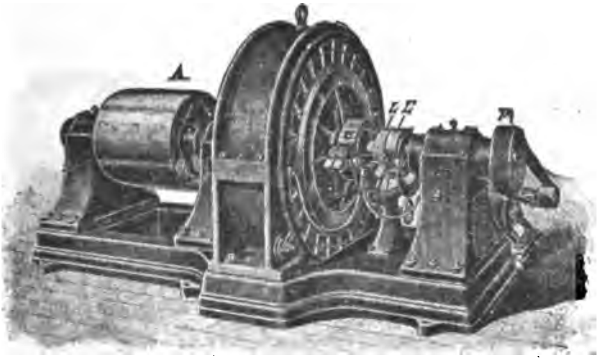

Fig. 42.—Compound-wound Alternator with Exciter and Commutator for a separate winding for armature.

Westinghouse Company's compound-wound, belt-driven alternator.

A compound-wound, belt-driven alternator, of the Westinghouse Company's type, capable of producing 90 K.W., with 16,000 alternations, at 1,000 revolutions per minute, is represented in Fig. 43. Here, necessarily, sixteen field-magnet poles are employed. These machines are wound for either 1,100 or 2,200 volts, as may be desired. It will be observed that the machine is of the two-bearing

Its laminated armature core.

type. The laminated armature core is obtained by employing punched disks of carefully selected sheet steel. Since the act of punching the disks tends to harden them, it is necessary to anneal or soften them by subsequent heating and gradual cooling. The armature core is provided with longitudinal perforations, that are connected with ducts perpendicular to the axis of the core, and so arranged that when the machine is running air is drawn through the core and thrown forcibly against the armature windings and the pole pieces, thus preventing too great increase of temperature. The coils of the armature are usually machine wound.

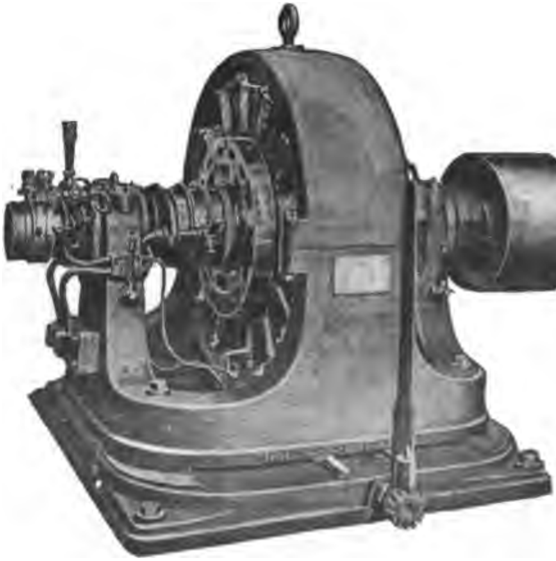

FIG. 43.—Compound wound, Belt-driven Westinghouse Company's Alternator, furnishing 16,000 alternations per minute.

A toothed-core armature, with machine-wound coils, for a machine of the preceding type, is represented in Fig. 44. Two or three concentric coils are employed for each pole. The field poles are built up of thin sheets of steel, which are then placed in the mold and cast in the iron yoke of the field frames, thus diminishing the loss due to eddy currents in the pole pieces. The field magnets are provided with two separate, independent windings, one of which is supplied with current from a separate exciter, while the other, called the compensating coil, is supplied with current from the armature of the alternator in the following manner: An independent winding is placed on what might be called the spokes of the armature.

Toothed-core armature for Westinghouse alternator.

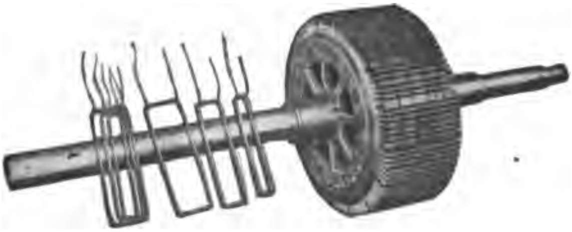

FIG. 44.—Toothed-core Armature for Westinghouse Company's Alternator, with a few machine-wound coils for same.

This winding acts as the secondary coil of the transformer, the primary of which consists of a few turns of wire through which passes the main current produced by the machine. The ends of the secondary winding of this transformer are connected with the segments of the small commutator placed on the shaft of the machine. By these means the current is commuted, and this current is supplied to the compensating coils of the field magnet. The employment of this method of compensation enables the alternator to be adjusted so as to supply a nearly constant voltage from practically no load to the full load of the machine.

Some details of compound-winding of alternator.

Alternators with revolving field magnet, and stationary armatures, or vice-versa.

An armature frame of a Westinghouse direct-driven alternator, or, as it is sometimes called, an engine type of alternator, is shown in Fig. 45. The great size of this armature frame may be estimated by comparing it with that of a man of average height standing inside the frame. In large sizes, the Westinghouse alternators are made of two different types; viz., those in which the armature rotates and the field magnets are fixed, and those in which the field magnets rotate and the armature is fixed. The armature frame shown in the above figure is of the second type.

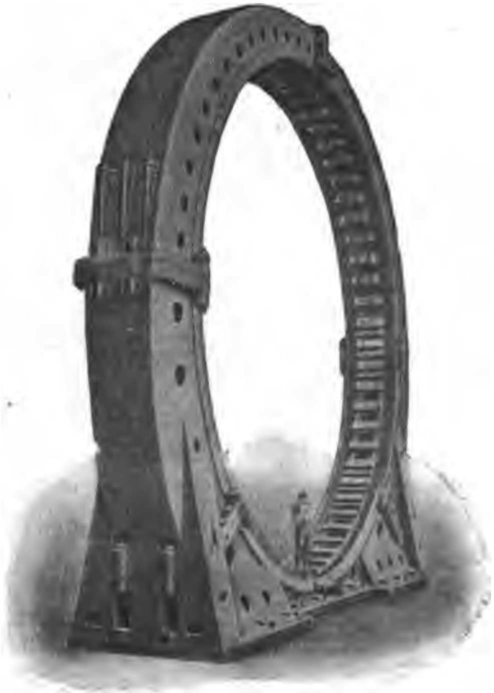

Fig. 45.—Armature frame for Westinghouse Company's 5,000 K.W. Alternator, built for the Manhattan Railway Company of New York City.

Bar winding of Westinghouse alternator armature

For high-voltage alternators, where the current produced is small, the armature coils consist generally of machine-wound coils, that are formed and insulated before being placed in the armature slots. For alternators of lower voltage, bars or straps of copper are employed, the end connections of the bar windings being secured to the bars after the conductors are placed in position. A portion of a bar winding of a rotating-armature alternator of the Westinghouse type is represented in Fig. 46.

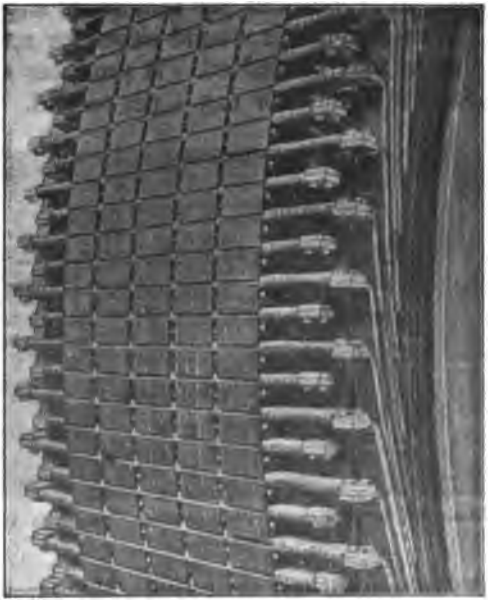

FIG. 46.—Portion of bar-wound rotating armature of Westinghouse Company's Alternator.

Where the armature is stationary and the field magnets revolve, the field magnets, when mounted on the armature shaft, act as a fly-wheel for the engine, the laminated plates being joined and held together by bolts.

A laminated pole piece for rotating field-magnet alternators is seen in Fig. 47.

General Electric Company's belt-driven compound-wound alternator.

A belt-driven alternator, as constructed by the General Electric Company, designed to operate at a speed of 750 revolutions per minute, is shown in Fig. 48. This machine is wound either for 1,150 or 2,300 volts, as may be desired. It produces 15,000 alternations per minute, or 125 ~ per second. Since it runs at 750 revolutions per minute, the number of its poles must be 20. The machine is compound-wound. One of the field-magnet windings is furnished with current from a separate exciter. The main driving pulley and the exciter pulley are seen at the left and right-hand side of the armature shaft respectively. The armature core is built up of laminations of a special soft steel. The armature is provided with perforations extending between the coils and through the core, so that, while running, a constant stream of air is passed through it, thus

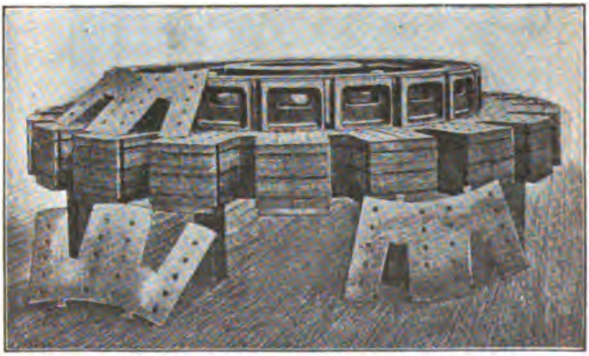

FIG. 47.—Laminated pole piece of Westinghouse Company's Rotating-field Alternator.

tending to keep the armature cool. The pole pieces of the field magnets are also laminated, and are cast into the armature core.

General Electric Company's direct-driven, compound wound alternator.

A direct-driven revolving-field alternator, of the General Electric Company's type, of 750 K.W. capacity, is shown in Fig. 49. This machine is wound for voltages of from 2,300 to 11,500 volts, as may be desired. At 140 revolutions per minute it produces 7,200 alternations per minute. These machines are suitable for the transmission of power, and for arc lighting purposes. The arrangements for the revolving field for a machine of smaller size are shown in Fig. 50. Here the laminated pole pieces are mounted on a steel ring.

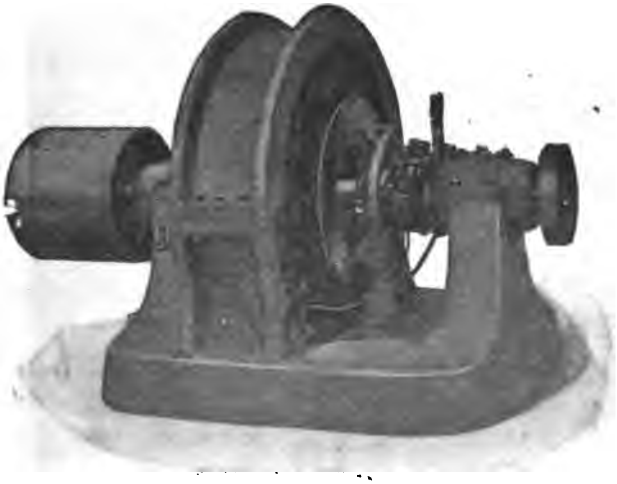

FIG. 48.—General Electric Company's Belt-driven Alternator.

Two different methods are employed by the General Electric Company for constructing the field-magnet coils of a revolving-field generator. For

General Electric Company's methods for winding field-magnet coils for revolving field generators.

the smaller machines the magnetizing coils are wound on spools, which are slipped over the pole pieces, and held in place by the enlarged pole tips. For large machines, where the magnetizing currents are heavy, the field-magnet coils consist of a single strap of copper, wound on edge, thus permitting the surface of each turn to be exposed to the air for cooling purposes. This method will be better understood from an examination of Fig.

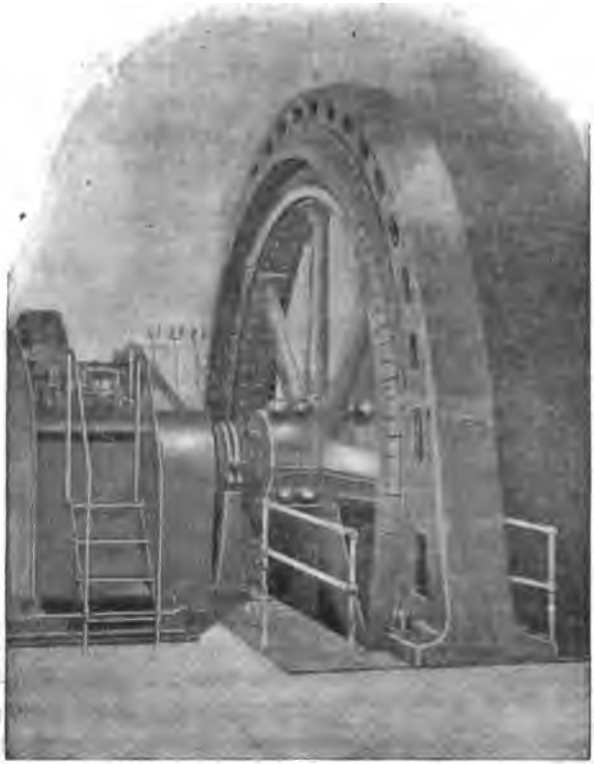

FIG. 49.—General Electric Company's Direct-driven Revolving-field Alternator, of 750 K.W. capacity.

Their method of cooling field-magnet coils.

51, where the copper strap is shown partly wound in a coil, and partly left unwound.

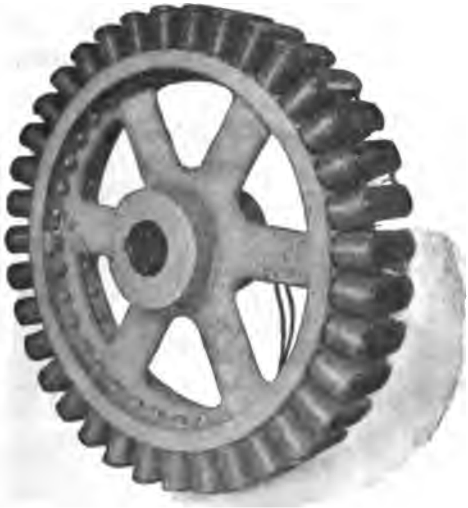

Fig. 50.—General Electric Company's revolving field for **Direct-driven** Alternator.

Stanley Electric Company's revolving field alternator.

A 2,000 K.W. revolving-field alternator, as made by the Stanley Electric Company, is shown in Fig. 52. An outside shell forms the support for the armature core punchings. These are held in place either by means of bolts, or by dovetails. Ven-

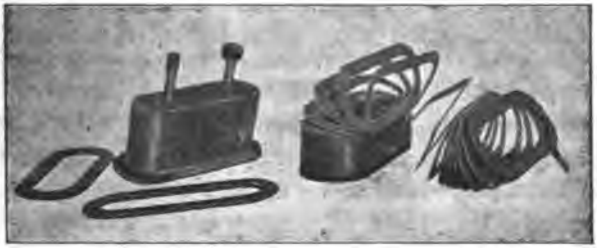

Fig. 51.—General Electric Company's method of winding field coils of Revolving-field Alternator.

tilating ducts are provided in the armature, so as to avoid undue heating. The armature coils are machine wound, and are wound for various pressures, up to as high as 12,000 volts. The field cores, like those of the preceding machines, consist

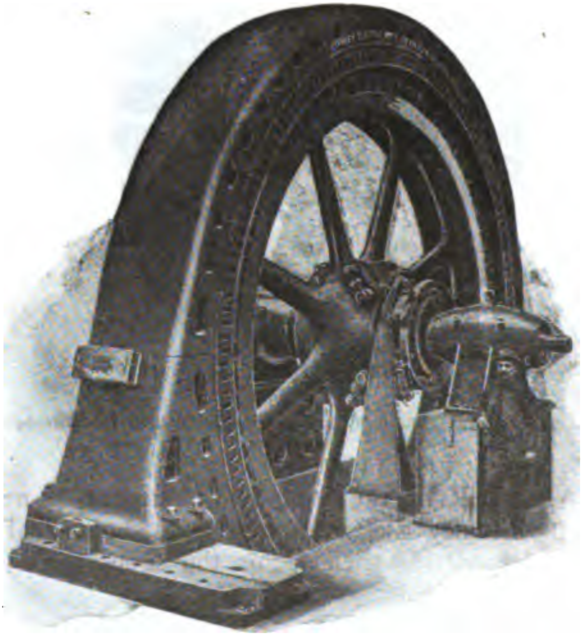

FIG. 52.—Stanley Electric Company's Revolving-field Alternator, of 2,000 K.W. capacity.

Absence of high pressure collecting rings.

of laminated pole shoes, that have the cores subsequently cast on to them. Since, in this machine, the armature windings are stationary, high-pressure collecting rings are unnecessary, the only sliding contacts being those required to supply the field coils with currents from the exciter.

CHAPTER VI

ALTERNATING-CURRENT TRANSFORMERS

"At the head of this long line of illustrious investigators stand the pre-eminent names of Faraday and Henry. On the foundation-stones of truth laid down by them all subsequent builders have been content to rest."—*The Alternating Current Transformers*: J. A. FLEMING

Alternating-current transformers.

IN many of the streets of our large cities apparatus resembling that seen in Fig. 53 may be observed, either on the tops of poles, or on the sides of houses. Such apparatus is connected at two of its terminals to wires that are supported on the street poles, and at its two other terminals, to wires that pass into the house or building. This apparatus is an alternating-current transformer. The wires from the street are connected to the ends of its primary coils, and those which enter the house or building to the ends of its secondary coils.

Faraday's early alternating-current transformers.

As we have seen, the alternating-current transformer was invented by Faraday during his investigations of the phenomena of dynamo-electric induction, the first transformer taking the shape of an iron ring. Let us suppose that, for the sake of obtaining the advantages of high electric pressures, a current of high E.M.F. has been transmitted from a distance over the line wires or conductors to the building where it is desired to be employed for the purpose of feeding incandescent electric lamps. Should the high-pressure current be sent directly through the lamp it would send so strong a current

Use of step-down transformers.

through the filaments that the lamp would be almost instantly destroyed. It is necessary, therefore, that the pressure or E.M.F. be lowered before being connected to the lamp terminals. This lowering or transformation of the pressure is readily done by the

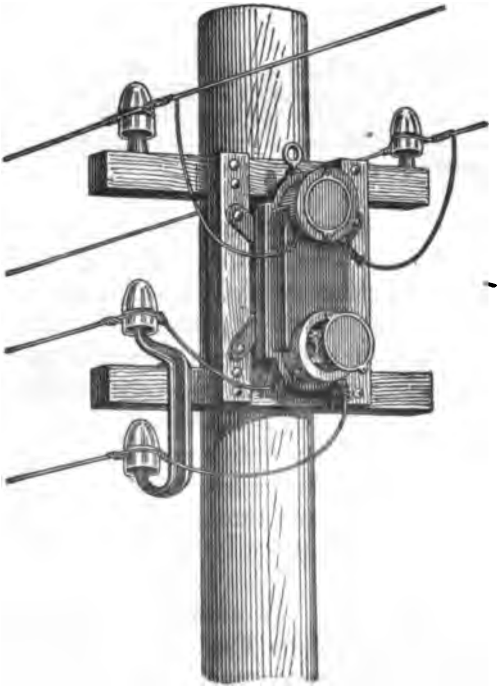

FIG. 53.—Alternating-current Transformer. Note the connections of the primary and the secondary coils.

use of step-down alternating-current transformers, by sending the high-pressure electric current through the primary coil P, Fig. 54, and connecting the secondary coil S of such transformer with the circuit in which the incandescent lamps are to be employed.

When the field magnets of an alternating-current dynamo are rotated before the coils of wire on the armature, alternating electric currents are generated in the armature coils with a frequency that will depend on the number of times a pole passes a coil. The value of the E.M.F.'s thus induced in any coil depends on the number of turns of conducting wire in such coil, and on its rate of cutting magnetic flux. When an alternating current is passed through the primary coils of an alternating-current transformer, the expanding and contracting lines of magnetic- [illegible] ire

Value of E.M.F.'s generated in secondary of transformer: how determined.

on e the primary coil, and P the secondary coil. p-
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queas a primary, and let the ends of the secondary te
E.IP be connected with the working circuit. The i-
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rel linked with ten times the number of turns in he
pr secondary coils. Consequently, the pressure will g-
cu ten times as great, or the 100 volts effective will as
a duce a pressure of 1,000 volts in the secondary ch
nd P. In other words, the pressure has been in es.
Fased. For this reason a transformer of this type re-
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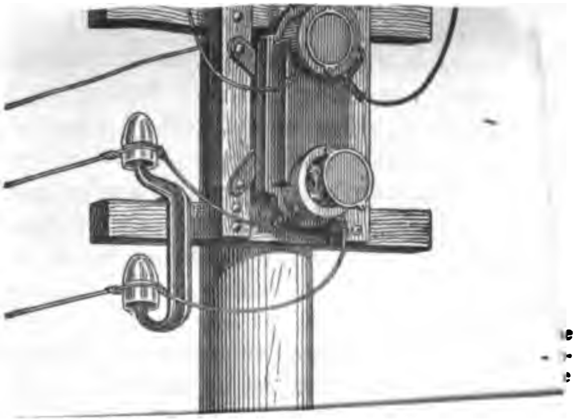
Secondary generators.

ondary coil to the armature coils. It is for this reason that an alternating-current transformer is sometimes called a secondary generator, although this term is also applied to other apparatus, as we shall hereafter describe.

In any transformer the passage of the electric current through the primary coils will produce, by mutual induction, in the secondary coils, alternating currents of the same frequency as those in the primary; so that, in the case before referred to, in connection with Fig. 54, the incandescent lamps will be operated by alternating electric currents of the same frequency, but of a lower pressure than those of the currents which are transmitted from the distant end of the line where they were generated.

General principle of action of a step-down alternating-current transformer.

As we have seen, the value of the E.M.F.'s induced in the secondary coil will depend on the relative number of turns of conducting wire in the two coils. If, for example, the secondary coil contains say one-tenth the number of turns of the primary, the flux passing through it only fills and empties one-tenth of the number of secondary turns that it fills in the primary coils. Consequently, the E.M.F.'s will have a value of but one-tenth the value of the E.M.F.'s in the primary coil. If, therefore, the E.M.F.'s impressed on the primary coils are 1,000 volts effective, then the E.M.F.'s generated in the secondary coils by mutual induction will be, approximately, but 100 volts. Since the number of turns of wire in the secondary coil is but one-tenth the number in the primary coils, the resistance of the secondary would be but one-tenth that of the primary. Consequently, the secondary would have to carry a current ten times as great as the current



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strength passing through the primary. In order to permit the secondary to readily carry such an increased current, it would, of course, be necessary to increase the area of cross-section of the secondary conductor. A transformer, in such a case, would transform the pressure from 1,000 volts to 100 volts, or it would lower the pressure. For this reason it is called a step-down transformer.

General principle of action of a step-up transformer.

Instead, however, of connecting the line circuit with the primary coil P, it may be connected with the secondary coil S. In other words, let S, Fig. 54, be the primary coil, and P the secondary coil. Let a pressure of say 100 volts effective be applied to S as a primary, and let the ends of the secondary coil P be connected with the working circuit. The flux passing through the turns of the primary are now linked with ten times the number of turns in the secondary coils. Consequently, the pressure will be ten times as great, or the 100 volts effective will produce a pressure of 1,000 volts in the secondary coil P. In other words, the pressure has been increased. For this reason a transformer of this type is called a step-up transformer.

Self-regulating action of alternating-current transformer.

'An extremely valuable property of the alternating-current transformer is found in the fact that it is self-regulating, as will be evident from the following consideration. The rapidly varying currents passing through the coils of the primary, set up, by self-induction, counter E.M.F.'s, as they are sometimes called, in its terminals, which will possess the same frequency as that of the E.M.F.'s that are producing it; that is to say, the coil, by its own self-induction, acts as a choking coil, and tends to limit the amount of current flowing through its own circuit. At the same time, the expanding and contracting lines of magnetic flux, passing through the secondary coils, set up E.M.F.'s therein by mutual induction. Now, while the terminals of the secondary coils remain open; or, in other words, while there is no load of lamps, or other apparatus, being operated by the secondary, its presence will have no effect on the amount of the reactance or the choking effect in the primary coils. As soon, however, as the terminals of the secondary coils are closed through the load of lamps, motors, etc., the current passing through the secondary coils will tend to magnetize the core of the primary coils in the opposite direction to that in which the primary current, passing through such coils, is magnetizing it. This will have the effect of decreasing the amount of the reactance or choking effect in the primary coils. Consequently, as the current flow through the secondary circuit becomes greater, a greater current will be permitted to flow through the primary circuit from the line conductor, and in this way the circuit becomes self-regulating, the variations in the choking effects thus permitting the coils automatically to regulate the amount of current passing through it to that required to supply the secondary circuit with the amount of current required to properly operate it.

How the self-regulation of the alternating-current transformer is obtained.

The simple ring-core transformer shown in Fig. 54 would not be economical in actual use, since the magnetic flux produced by the primary current would not all pass through the wires of the secondary; or, in other words, the magnetic leakage would be great. In order to avoid this, the primary and secondary coils are placed as near together as practicable. The core is so shaped as to provide a magnetic circuit which shall direct as many of the lines of magnetic flux through the loops of the coil as possible.

Low efficiency of ring-core transformer.

The simple form of transformer shown in Fig. 195, Vol. I, would also be objectionable from the fact that, possessing a high magnetic leakage, it would require the strength of the magnetizing current to be correspondingly increased, in order to cause sufficient magnetizing flux to pass through the coils. This objection would be greatly remedied, as has been done by Varley, by bending the soft iron wires employed for the laminated core over one another, as in Fig. 55, thus surrounding the coils by an iron shell. Here the primary and secondary coils are placed one over the other. The iron of the core, however, that passes outside the coil, affords an increased radiating surface by the loss of heat. By placing the primary and secondary coils side by

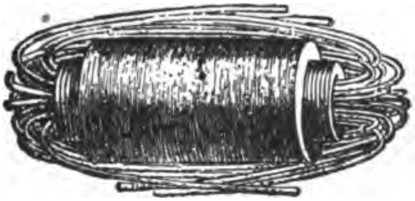


FIG. 55.—Varley's simple form of Shell Transformer. Note the fact that the bending of the iron wires ensures what is practically a closed magnetic circuit.

Two types of transformers; viz. core transformers and shell transformers.

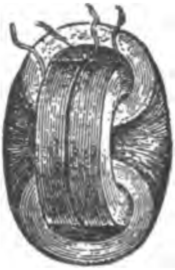


FIG. 56.—Zippernowski's shell form of Transformer. Note the position of the primary and secondary coils.

side, as in Fig. 56, as was done by Zippernowski, and winding a core of iron wire through and over them, we have a form of transformer that possesses many advantages. There thus arise two types of transformers; viz., core transformers, such as shown in Fig. 18, and shell transformers, as shown in Fig. 56. Many excellent transformers are built in accordance with both of these types.

It is a matter of the greatest importance that the temperature of a transformer should be kept as low as possible. Consequently, the core must be carefully laminated, so as to prevent undue heating by the setting up of eddy currents. This is done by building the core of laminations, or separate sheets of the best softened iron of about one-twentieth of an inch in thickness. In transformers of the core type the core is built up of rectangular punchings, as shown in Fig. 57. In order to diminish the disagreeable humming noise, so common in transformers, both the separate laminations of the core and the coils on the core are bound firmly together,

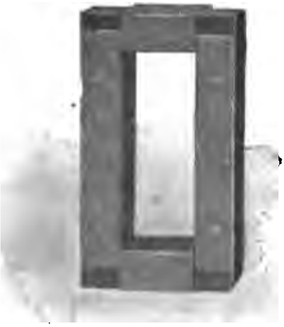


FIG. 57.—General Electric Company's laminated core for Core Transformer.

Lamination of core of transformer.

so as to prevent vibrations due to magnetic attractions and repulsions.

In a core type of transformer, as manufactured by the General Electric Company, and known as their Type-H transformer, the secondary coils are wound directly on the core, and the primary coils are wound directly on top of the secondary, as shown in Fig. 58, where a cross-section of the coil and the core shows the construction of this type of

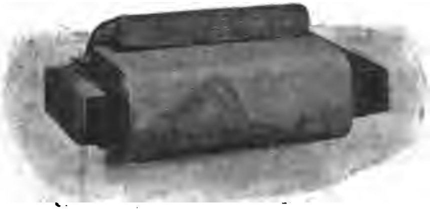


Fig. 58.—General Electric Company's Core Type of Transformer. Section showing relative positions of core and coils.

General Electric Company's Type-H core transformer.

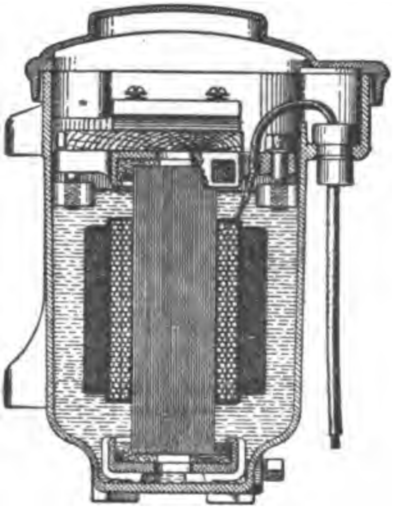


Fig. 59.—General Electric Company's Oil-cooled Type-H Transformer. (Sectional view.)

apparatus. Where oil is employed for cooling purposes, the transformer is placed in an outer iron core, and surrounded by oil, as seen in Fig. 59. Since doubling the size of a transformer causes the current it produces to increase approximately sixfold, while the surface from which the heat is radiated is only increased fourfold, in transformers of large size especial care is necessary in order to avoid undue heating. Such transformers are kept cool either by passing air, oil, or water through them, thus giving rise to types of transformers known as air-cooled, water-cooled, and oil-cooled transformers. At the same time, the iron case which sur-

Air-cooled, oil-cooled, and water-cooled transformers.

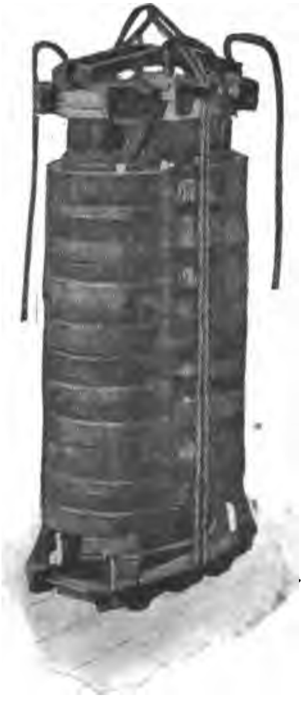


FIG. 60.—General Electric Company's Oil-cooled Type-H Transformer. (With case removed.)

rounds the transformers, and contains the liquid, is provided on the outside with convolutions, so as to present as great an extent of air surface, for radiation, as possible. An oil-cooled General Electric Company's transformer of the type H, or core type, is shown in Fig. 60, with the case removed, so as to show some details of construction. An oil-cooled transformer, when well designed and constructed,

General Electric Company's oil-cooled transformer.

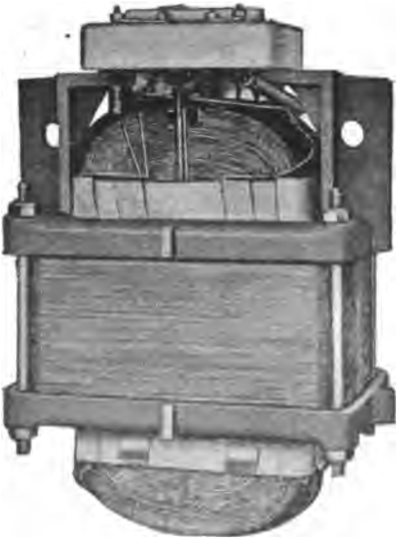


FIG. 61.—Westinghouse Electric Company's Shell Type of Transformer.

should not increase in temperature beyond 125° F. Water-cooled transformers may be built so as not to increase in temperature beyond 122° F.

Shell transformers are made in various forms. That shown in Fig. 61 is the form adopted by the Westinghouse Electric Company. Here the coils are surrounded at their central portions only by the laminations of an iron core, constructed as shown

Westinghouse Company's shell type of transformer.

in Fig. 62. The ends of the coils projecting beyond the iron core are spread apart, so as to present an extended surface for the cooling action of the oil or water.

General Electric Company's shell transformer.

A form of shell transformer, as constructed by the General Electric Company, is seen in Fig. 63.

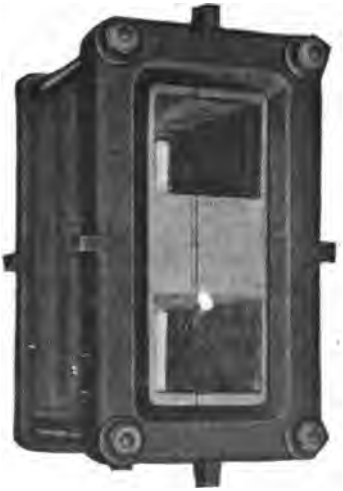
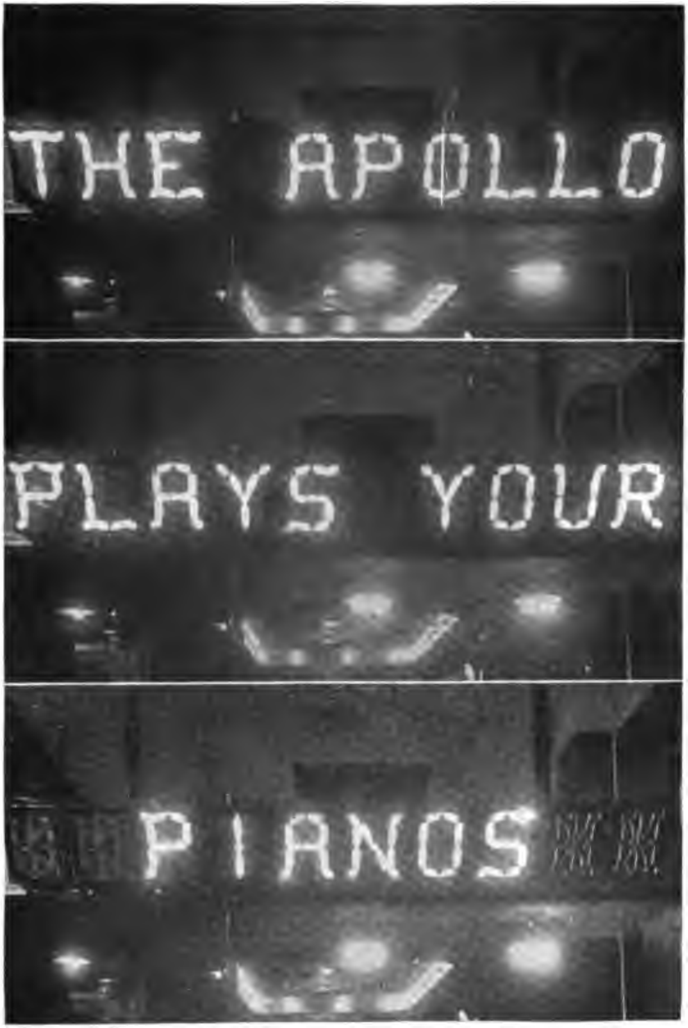


FIG. 62.—Westinghouse Electric Company's laminated core for Shell Transformer.

Here the primary and secondary coils are assembled as shown in the figure, with air spaces left between them for ventilation.

Stanley Electric Company's shell transformer.

A type of shell transformer, as constructed by the Stanley Electric Company, is shown in Fig. 64. Here a laminated core of sheet iron is seen partly surrounded by coils, the upper and lower ends of which are exposed either to air, water, or oil, employed for cooling purposes. The coils are



THE ELECTRIC "TALKING SIGN"

An ingenious form of night advertising in which different combinations of incandescent lights spell out phrases and words, the legend changing automatically every few moments. Forty different legends can be flashed from the one monogram

separately wound and insulated, and are placed inside one another, as shown in Fig. 65.

Switch for variously connecting separate primary and secondary transformer coils

In nearly all cases the primary and secondary circuits consist of a number of separate coils, separately wound and insulated, and so arranged as to be readily connected together in series, parallel, etc., so as to vary the ratio of transformation.

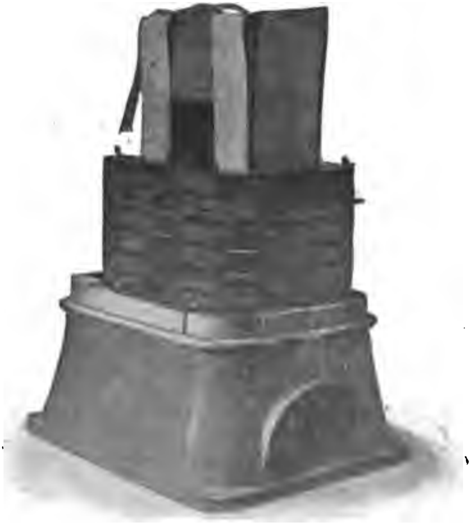


FIG. 63.—General Electric Company's Shell Type of Transformer.

This coupling of the coils is generally so arranged as to be readily effected by the turning of a switch handle. An arrangement of this character is shown in Fig. 66.

Where the line conductors, employed for transmitting the electric currents through the transformer, are placed underground, it is more convenient to place the transformer also in some

Subway transformers.

convenient underground space; such, for example, as in manholes connected with subways in which underground conductors are placed. Since such spaces are limited, any increase in the size of the transformer is generally obtained by an increase in its length. Since the manholes are frequently filled with water, it is necessary that the transformer be made water-tight. Moreover, since such transformers are often connected with the mains for the entire twenty-four hours of the day, it is necessary that the transformers must heat as little as possible, since the subways are generally air-tight. An oil-cooled type of the General Electric Company's subway transformer is shown in Fig. 67.

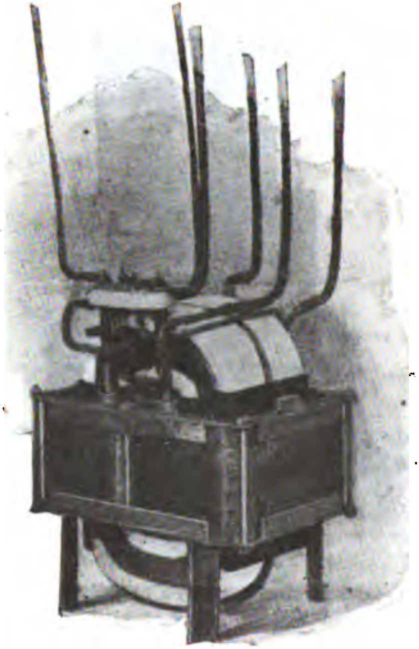


FIG. 64.—Stanley Electric Company's Shell Type of Transformer.

Transformer losses.

The various losses that occur in alternating-current transformers are as follows: those due to the copper loss, or to the currents being transmitted through the conducting coils against their

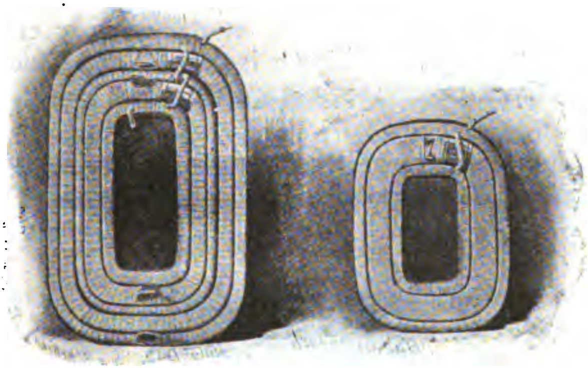


Fig. 65.—Stanley Electric Company's Transformer. Primary and secondary coils for same.

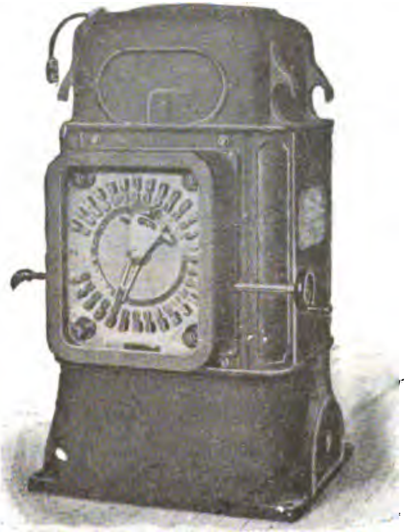


Fig. 66.—Dial switch on General Electric Company's Transformer, for adjustable ratio of transformation. The turning of the switch han-

ohmic resistance; those due to setting up of eddy or Foucault currents in the iron cores; those due to hysteretic losses, together with the loss due to the small current which flows in the primary circuit when the secondary circuit is opened, and which is sometimes called the leakage current.

The efficiency of transformers can be made as high as 98 per cent for full load. At one-quarter load they may have an efficiency of from 94 to 95 per cent. Although this efficiency is very high, yet, in many cases, such, for example, as where transformers are feeding lamps, the loss in the aggregate is comparatively high, since the transformers are run for a great part of the time on a very small load.

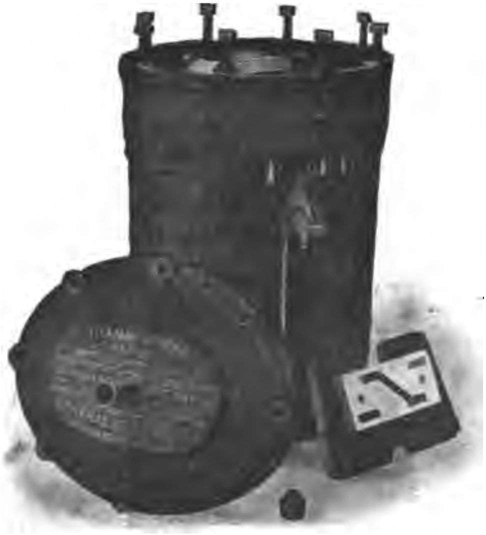


FIG. 67.—General Electric Company's Oil-cooled Type of Subway Transformer.

Efficiencies of transformers.

Transformers are constructed with various frequencies. These are generally from 40 to 140 periods per second, or from 4,800 to 16,800 alternations per minute.

Transformer frequencies.

As in the case of alternators, transformers are built so as to supply constant currents as well as constant potentials. The former are employed to feed incandescent and arc lamps in series, while the latter are for supplying multiple circuits generally.

Constant-current and constant-potential alternators.

The high pressure employed in alternating currents renders them extremely dangerous. Consequently in order to avoid fatal accidents, every precaution should be taken to prevent the high tension circuit from being connected with the low tension circuit. This is accomplished by means of various devices for automatically grounding the secondary circuit as soon as its pressure becomes dangerous, or by means of a grounded metallic shield interposed between the primary and secondary circuits. It may also be avoided by permanently grounding the secondary circuit.

Safety devices for transformers.

CHAPTER VII

EARLY HISTORY OF ELECTRIC LIGHTING

> "Night's candles are burnt out, and jocund day
> Stands tiptoe on the misty mountain-tops."
> —*Romeo and Juliet,* Act I, Scene V

Prometheus, the world's great benefactor and early inventor.

PROMETHEUS, son of Iapetus, who is reputed to have stolen the sacred fire from heaven and bestowed it upon mortals, was, according to general mythological belief, badly treated for this great benefaction. At the command of the incensed Jupiter, he is said to have been chained for 30,000 years to a rock on Mount Caucasus, where a vulture was commanded to feed each day on his liver, which grew again during the night. Prometheus must indeed have suffered from an abnormal growth of the liver, and a diseased condition of this organ generally. As is well known in medical science to-day, there is a pathological condition of the human body called jaundice, which is due largely to a diseased liver. This disease tends to pervert the judgment, and cause subjects to be regarded mentally in a false light. Poor Prometheus, jaundiced as he may have been, was far less afflicted with this dire disease than those who judged him so uncharitably, and so utterly failed to recognize the great benefit that he bestowed upon mankind. Had he been judged in the light of to-day, he would, beyond doubt, have been heralded as an inventor of the first water, for he it was who first discovered the great value of fire, Prometheus, the father of artificial illumination.

and taught mankind how to obtain it. It was he, too, who, in all probability, also taught mankind how to extend the range of the articles suitable for their food. But the great benefit which Prometheus bestowed on mankind by his discovery was the great feat he thus achieved, by the use of artificial light, of extending the day far into the night.

Electric lighting one of the electric arts.

The burning fagot, caught hurriedly from the blazing fire, was man's first portable light. Although extremely rude, as compared with our modern means of artificial illumination, yet for its time it was a great achievement. As is well known, this first crude artificial light was followed by various improvements in oil and gas lighting up to the present day, when electric lighting has reached a stage in which it can properly be regarded as one of the arts.

From the dull glare of the burning fagot to the brilliant light of the voltaic arc.

It was a great step in the world's progress when, by the introduction of gas lighting, it became possible to properly light the streets of large cities during the night. In these later days, with the general introduction of electric lighting, gas lights for streets have become anachronisms, and have been replaced very generally by various forms of arc or incandescent lighting.

Lightning the world's first electric light.

The first electric light that the world ever saw was produced by the fitful flashings of the lightning bolt. Necessarily, as a source of artificial illumination, such lighting was valueless, although doubtless, at times, to the navigator on a rocky coast, the momentary flashes gave sufficient evidence of approaching danger to render them far from useless as a means of illumination.

A minute electric spark the first herald of the splendors of the electric light.

The earliest electric light produced by man consisted of the electric spark in some form or other. From what we know of the early history of frictional electricity, it must indeed have been a tiny spark that thus first heralded the great things that were to come in the way of artificial illumination. Just who was the first who produced this early spark is unknown. There is no evidence that Thales ever got beyond the simple attraction of light bodies by his little piece of rubbed amber. Eustathius, Bishop of Thessalonica, writing about 1160 A.D., asserts that "Walimer, the father of Theodoric, who conquered, as they say, the whole of Italy, used to emit sparks from his own body; and a certain ancient philosopher says of himself, that once, when he was dressing and undressing himself, sudden sparks were emitted occasionally, crackling; and sometimes, he says, entire flames blazed from him, not burning his garment."

A luminous writer and philosopher

Guericke and the early dawn of the electric light.

As we have already seen, the first to actually produce what may be called an electric light was Otto Guericke, a contemporary of the celebrated Robert Boyle. Guericke had invented a form of frictional electric machine, in which a globe of sulphur was electrified by the friction of the hand held against it. By this means Guericke obtained, on electrifying the globe, flashes of electric light. At a later date, 1705, Hawkesbee, in some curious experiments on the motions of mercury in vacuous spaces, produced flashes of light in such vessels, that gave effects which he likened to lightning flashes. We now understand his experiment. He had actually produced at this early date, although of course in an extremely imperfect form, one of the modern types of electric lighting, now known as the

Hawkesbee's early form of vacuum-tube lighting.

vacuum tube light. A great increase in the brilliancy of the light produced by the electric discharges came with the discovery of the Leyden jar, and the construction of powerful Leyden-jar batteries. Here the powerful discharges produced momentary arcs of great brightness, and the light so emitted momentarily illumined surrounding objects. Naturally there was thus suggested the possibility of obtaining artificial illumination by electric means.

Strong momentary illumination produced by discharges of Leyden-jar batteries

Sir William Watson appears to have been the first who actually observed the electric spark produced by the discharge of a Leyden jar. Passing such discharges through a vacuous space, some ten inches in length, he obtained therein "a mass of very bright embodied fire." Von Marum, in 1736, constructed a large frictional electric machine, from which he was able to obtain sparks that would pass freely in ordinary air through distances of from fifteen to eighteen inches. By such discharges through a vacuum tube, some seven feet in length, he was able to obtain a continuous stream of splendid purple light.

Watson's "mass of bright embodied fire"

Von Marum's luminous vacuum-tube discharges.

Shortly after the discovery of the Leyden jar, experiments were made in Holland and elsewhere on the deflagration or volatilization of different metallic substances by the discharge of powerful Leyden-jar batteries. A powerful Leyden-jar battery, made for the Tylerian Society, at Haarlem, when employed with the Von Marum frictional-electric machine above described, gave magnificent results, which are thus described by Preece, in his revised edition of Noad's "Electricity":

Powerful Leyden-jar battery in Haarlem.

"By thus multiplying the number of jars, we have it in our power to accumulate electricity to

Description of powerful Leyden-jar battery of the Tylerian Society of Haarlem.

an extent limited only by the charging power employed. A prodigious apparatus was constructed toward the end of the last century by Cuthbertson for the Tylerian Society at Haarlem. It consisted of one hundred jars, each of five and one-half square feet, so that the total amount of coated surface was 550 square feet. This battery, when charged with a very powerful machine, produced the most astonishing effects. It magnetized large steel bars, rent in pieces blocks of boxwood four inches square, melted into red-hot globules iron wires 25 feet long and $\frac{1}{140}$th of an inch in diameter, and dissipated, in a cloud of blue smoke, tin wires eight inches long and $\frac{1}{18}$th of an inch in diameter."

During these discharges momentary metallic arcs of great brilliancy were necessarily produced. The light so caused in all probability reached a greater intensity or brilliancy than any that had heretofore been obtained.

Influence of the voltaic battery on the problem of electric lighting.

But so long as the source of electricity was limited to any of the electric machines then known, it was impossible to produce what might properly be regarded as an electric light. When, however, the great discovery of Volta, in 1796, gave to the world a new electric source in the shape of the voltaic battery, there came what may be regarded as the true beginning of the history of electric lighting.

Formation and nature of the voltaic arc.

When the terminals of a powerful voltaic battery are slowly separated, a brilliant arc, called the voltaic arc, is established between them. This arc consists of an intensely heated mass of glowing, incandescent vapor, formed by the volatilization of the materials of the terminals between which the electric current passes. The glowing mass forms a semi or partial conductor of electricity. If the terminals are not separated too far, and the E.M.F. produced by the battery does not vary, the voltaic arc will continue between the separated terminals for a long time.

Davy and the carbon voltaic arc.

Shortly after Volta's discovery large voltaic batteries were constructed by numerous investigators in different parts of the world. On opening the circuit of such batteries a momentary flash must necessarily have occurred. Sir Humphty Davy, whose brilliant discoveries in the domain of the science of electro-chemistry we shall shortly describe, employed voltaic batteries for a variety of purposes, and, indeed, as early as 1800, had obtained a small carbon arc by the use of a comparatively small voltaic battery. Davy has been generally credited as the discoverer of the carbon voltaic arc, and, consequently, as the discoverer or the practical beginner of the art of electric arc-lighting. A careful examination of the literature of this period, however, does not appear to justify this claim, although Davy was, probably, among the first to employ carbon for this purpose. Indeed, Davy himself does not appear to make any such claim. He may, however, properly be given the credit for first exhibiting to the general public the splendors of the carbon voltaic arc, and the wonderful possibilities of such light as a source of artificial illumination.

Davy's early public exhibition of the splendors of the carbon voltaic arc.

Davy formed his arc between terminals or electrodes consisting of pieces of hard carbon, such, for example, as pieces of well burned charcoal. Under these circumstances, the length of the arc was comparatively great, and the light produced far more brilliant than if electrodes of metallic substances

One of the causes of the bow or arc shape of the mass of glowing carbon vapors.

had been used. The name arc was applied to the mass of glowing carbon vapor on account of the shape that it assumed, the arc being drawn by Davy between two carbons placed in a horizontal position. Under these circumstances, the currents of heated air rise between the carbon, causing the arc to bend upward. It was for this reason called the carbon voltaic arc.

Davy's public demonstration of the splendors of the carbon voltaic arc was made in 1809, at a public lecture, delivered at the Royal Institution of London. A description of this demonstration is thus given by Singer, in a book entitled "The Elements of Electricity and Electro-Chemistry":

Singer's description of Davy's public exhibition of the carbon voltaic arc at the Royal Institution of London in 1809.

"With a large apparatus employed at the Royal Institution, which extends to 2,000 pairs of four-inch plates, points of charcoal were brought within a thirtieth or fortieth of an inch of each other before any light was evolved; but when the points of charcoal had become intensely ignited, a stream of light continued to play between them when they were gradually withdrawn even to the distance of near four inches. The stream of light was in the form of an arch, broad in the middle and tapering toward the charcoal points; it was accompanied by intense heat, and immediately ignited any substance introduced into it; fragments of diamond, and points of plumbago disappeared, and seemed to evaporate, even when the experiment was made in an exhausted receiver; though they did not appear to have been fused. Thick platina wire melted rapidly, and fell in large globules; the sapphire, quartz, magnesia, and lime were distinctly fused.

"In rarefied air, the discharge took place at a greater distance, and the beam of light was made to pass through an interval of six or seven inches."

The carbon voltaic arc is to-day so common a thing that it fails to excite admiration any more than does such a magnificent object as the sun itself. But in the early days when Davy thus publicly showed the voltaic arc, the greatest astonishment and excitement were produced in the public mind. The light was compared, as far as its intensity was concerned, with the light of the full day's sun. The 200 series-connected voltaic battery employed by Davy gave an E.M.F. sufficient to maintain the arc through a column of incandescent carbon vapor about three inches in length. The light emitted was of dazzling splendor. The intense heating power of the arc was especially noted. Substances with extremely high melting-points, when introduced into the intense heat of the voltaic arc, were readily fused. Under these circumstances platinum melted as readily as wax in the flame of a candle. Small pieces of charcoal, when traversed by the current, were heated to intense whiteness. All who saw the light believed that the problem of a new artificial illuminant had been solved. Nor were they mistaken, save in the belief that the light was ready for commercial use.

The dazzling splendors of the carbon voltaic arc.

Davy himself thus describes the experiments tried with the carbon arc at this public exhibition, in a scientific paper entitled "An Account of Some Experiments on Galvanic Electricity made in the Theatre of the Royal Institution":

"The apparatus employed in these experiments was composed of 150 series of plates of copper and zinc of four inches square, and fifty of zinc and silver of the same size. The metals were carefully cemented in four boxes of wood in regular order, after the manner adopted by Mr. Cruickshank, and the fluid made use of was water combined with about $\frac{1}{100}$ part of its weight of nitric acid.

Davy's account of the demonstration in the theatre of the Royal Institution.

"The shock taken from the batteries in combination by the moistened hands, was not so powerful but that it could be received without any permanently disagreeable effects. Charges were readily communicated by means of them to coated jars, and to a battery; but in this case the effects produced by the electricity were much less distinct than in the case of immediate application.

"When the circuit in the batteries was completed by means of small knobs of brass, the spark perceived was of a dazzling brightness, and in apparent diameter at least one-eighth of an inch. It was perceived only at the moment of the contact of the metals, and it was accompanied by a noise or snap.

The splendor of the carbon arc.

"When instead of the metals, pieces of well-burned charcoal were employed, the spark was still larger and of a vivid whiteness, an evident combustion was produced, the charcoal remained red hot for some time after the contact and threw off bright coruscations.

"Four inches of steel wire $\frac{1}{70}$ of an inch in diameter, on being placed in the circuit became intensely white hot at the point of connection, and burned with great vividness, being at the same time red throughout the whole of its extent.

Great deflagrating or heating power of the voltaic arc.

"Tin, lead, and zinc, in thin shavings were fused and burned at their points of contact in the circuit, with a vivid light and with a loud hissing noise. Zinc gave a blue flame, tin a purplish, and lead a yellow flame violet at the circumference.

"When copper leaf was employed it instantly inflamed at the edges with a green light and vivid sparks, and became red hot throughout the whole of its diameter when it did not exceed four inches.

"Silver leaf gave a vivid light, white in the centre and green toward the outline, with red sparks or coruscations. Platina in thin slips, when made to complete the circuit, became white hot, and entered into fusion, and gave scintillations at the edges; but whether any part was converted into oxide could not be accurately determined.

Some peculiar colors of metallic voltaic arcs.

"When gold leaf, attached by gum-water to white paper was burned by the spark, the light was of a bright yellow and the noise comparatively loud; the gold was converted into an oxide of purplish brown color, which firmly adhered to the paper, and by regulating the course of the spark by means of the communicating wire, letters and figures were traced by the combustion, which appeared semi-transparent when exposed to the light.

"When the galvano-electric spark was taken by means of two pieces of charcoal partially covered with cotton, the cotton was readily inflamed; whether in its simple state, or sprinkled over with resin or sulphur.

"Fulminating mercury and gunpowder were deflagrated by means of the communication of charcoal; and hydrogen and the compound of inflammable gases were readily made to burn when simply in contact with the atmosphere and to detonate when mixed with oxygen.

"A few only of these results have any claim to originality. On the phenomena of the combustion of bodies by galvanism we have been already furnished with many striking experiments, by our own countrymen, and by the German and French philosophers. And after the path is once discovered in researches of this kind, to pursue it requires but little ability or exertion. An account of common facts, under new circumstances, particularly when they are accompanied by striking phenomena, can however never be wholly useless; and it sometimes gives a novel interest to the subject, and tends to awaken curiosity."

It will be observed here that Davy himself does not claim the discovery of the carbon arc. Indeed, the remarks made toward the close of the above quotation would appear to be a denial of any such claim.

Extinction of voltaic arc by the approach of a magnet.

The highly heated incandescent substances that constitute the voltaic arc form, in reality, a movable conductor, through which a powerful electric current is passing. Consequently, like all such conductors, voltaic arcs are readily attracted and repelled by the neighborhood of other active conductors, or by magnets brought near them. The ability of a magnet to thus deflect or turn a voltaic arc out of its original position, was first observed by Davy. In order to show this phenomenon, let the carbon arc, established between two carbons, be brought between the poles A and B, Fig. 68, of a powerful electro-magnet. Then, instead of burning quietly between the carbons, the arc will be violently repelled, and will assume a horizontal position closely resembling the flame of a blow-pipe. At the same time. the arc increases in length, some-

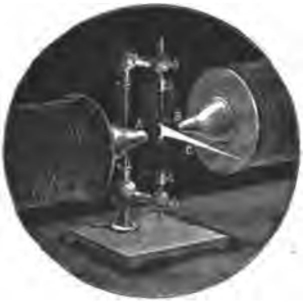


FIG. 68.—Deflection of Voltaic Carbon Arc by Flux of Electro-magnet. Note the blow-pipe appearance of arc. Note the fact that the arc C increases in length and is deflected at right angles to the direction of the magnetic flux or streamings.

times to an extent ten times as great as its original length. A hissing noise is heard, and, if the strength of the magnetic flux is sufficiently great, the arc will be extinguished with a loud report. In a similar manner, a strong current of air directed against the arc will blow the arc out.

Elihu Thomson's magnetic blow-out.

Since the heat of a voltaic arc is so great, when arcs are accidentally established in any part of a circuit, considerable damage will result unless they are promptly extinguished. The ability of a magnet to thus extinguish or blow out a voltaic arc has been ingeniously applied by Elihu Thomson and others in a piece of apparatus called an automatic or magnetic blow-out.

Striking or establishment of voltaic arc by Leyden-jar discharge.

It is the mass of highly heated volatilized carbon or metallic vapor that conducts the electricity, thus permitting the current to pass through what would otherwise be a path of extremely high resistance. Consequently, in order to form an arc, the carbons are first brought into contact, and then slowly separated. Anything that will establish the arc, even if but for a moment, permits the current to pass so as to fill the intervening space with glowing vapor, thus permanently establishing the circuit. For example, if the carbons are not separated too far, the arc may be established between them by the discharge of a Leyden-jar. All such disruptive discharges, as we have already seen, are attended by the formation of a mass of incandescent metallic vapor, and this, though it exists but for a few moments, is sufficient to permit the current from the battery, or other source, to pass between the carbons, and thus permanently establish, or, as it is frequently called, "strike the arc" between them. Of course, when the E.M.F. employed is sufficiently high, the arc may be established without first bringing the terminals together, since, under such circumstances, disruptive discharges would take place that would be able to pass through the intervening air space.

Formation of voltaic arcs under water, or in vacuous spaces.

Since the carbon voltaic arc is caused by the heating of the carbon vapor by the electric current, and is not at all dependent on the oxygen of the air, it is possible to form a carbon arc under the surface of water or other liquids, as well as in empty or vacuous spaces. Davy formed minute voltaic arcs under the surface of various liquids, such as different oils, ether, alcohol, and nitric and sulphuric acids. A carbon arc, if not too long, will burn for some time below the surface of water. Arcs are also readily formed in a vacuous space. Here, when the vacuum is good, a smaller E.M.F. is required to establish the arc across the intervening space than would be if such space were filled with air or gas at ordinary atmospheric pressures.

CHAPTER VIII

PHYSICS OF THE CARBON VOLTAIC ARC

"Double, double, toil and trouble;
Fire, burn, and cauldron, bubble."
—*Macbeth*, Act IV, Scene I

THE voltaic arc produced by the passage of a continuous electric current between carbon points or electrodes, possesses a number of exceedingly interesting physical properties that it will be necessary carefully to examine. Let us suppose that two carbon electrodes are placed one directly above the other, as is represented in Fig. 69; and that the current flows out of the upper carbon into the lower carbon; or, in other words, that the upper carbon is positive and the lower carbon negative; then a brilliant mass of bluish flame is formed between the carbons. This mass, though sometimes extending directly between the carbons, more frequently possesses the form of an arc, being bent toward one side or the other, due either to the magnetic flux of the earth or to the presence of the column of heated air when the carbons are horizontal. It does not maintain a constant position between the two carbons, but rapidly changes, now burning at one portion of the edge, now rapidly changing to the other side, and again, travelling regularly, but slowly, around the edge of the carbons. This shifting of the arc is objectionable from the fact that it causes a flickering or unsteadiness of the light. It is more marked when the carbons

Travelling of the carbon voltaic arc.

Unsteadiness of the arc light.

are far apart, and when the current strength undergoes marked variations from time to time.

Change in appearance of positive and negative carbons during use in arc.

After the circuit has been maintained for some time, the extremities or ends of the carbons will be observed to differ greatly in shape. The upper or positive, out from which the current flows, becomes cup-shaped at its lower extremity, and is hollowed out at this point in a small crater or cavity. The lower carbon, or that into which the current passes, will, on the contrary, be seen to have a small hillock, projection or nipple formed at that portion of its end which lies directly opposite the crater in the positive carbon.

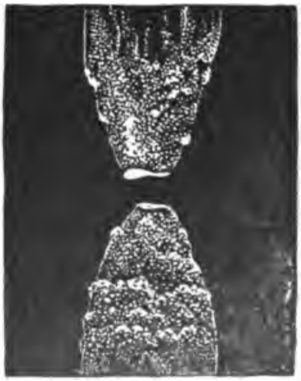


FIG. 69.—General Appearance of Image of Carbon Voltaic Arc Projected on Lantern Screen.

Positive crater and negative nipple.

The light emitted by the carbon arc is too bright to be safely examined directly by the eye; but, if it be looked at through a pair of dark glasses, it will be observed that, though all parts of the ends of the carbon are much brighter than the mass of glowing vapor or the arc proper that is formed between them, yet the positive carbon, generally, is much brighter than the negative carbon; and that, moreover, all parts of the positive carbon are not equally bright, the brightest part of this carbon being in its crater or cavity. Since, as is well known, the ability of a heated body to emit or give off light increases rapidly with its temperature, this simple observation establishes the fact that the positive carbon is much hotter than the negative carbon, and that the point of highest temperature in the positive carbon is situated within the arc or crater at its lower end.

Crater in positive carbon place of highest temperature in carbon arc.

When a carbon voltaic arc is formed in air, the highly heated carbons will be burned just as would coal in a stove. An examination of the mass of glowing vapor will show that its inner part is of a violet hue, and that outside of this portion is a faintly luminous flame, due to the presence of carbon monoxide, the gas which may be seen on the surface of a hard-coal fire where the amount of air is insufficient to completely consume the carbon. Outside of this envelope, that is, on the portion of the arc proper where the carbon monoxide comes in contact with the oxygen of the air, a brighter flame of carbon dioxide can be seen. The consumption of the negative carbon is due entirely to this burning in the air, either in the form of carbon monoxide or of carbon dioxide.

Three distinct portions of voltaic arc proper.

The mass of glowing carbon vapor consists entirely of volatilized carbon, except at the surface layers, where the two varieties of oxide of carbon before referred to exist. No combination or burning occurs within the central portions, since no air can penetrate within this space. Even if it could do this, the temperature of the arc is so high that carbon monoxide would be unable to exist, since it

Main body of voltaic arc formed of mass of glowing carbon vapor.

would be disassociated or decomposed by the high temperature. An examination of the ends of the carbon will show melted globules irregularly distributed over those parts of the surface that have become highly heated. These globules are due to various mineral impurities in the carbons.

Flickering of arc light due to changes in position of positive crater.

As the position of the arc changes from time to time, the position of the crater or cavity at the end of the positive carbon also changes, and since this is the brightest spot on the carbon, the flickering before referred to necessarily results. The amount of this flickering increases with the impurities present in the carbon, so that the purer the carbons employed, the less will be the shifting of the arc, and, consequently, the steadier will be the light. Since this shifting is also due, to a great extent, to an extended area of cross-section, thinner carbons will burn more steadily than thick heavy carbons, they will, however, consume more rapidly and thus require more frequent renewals. The use of cored carbons, that is, carbons the central portions of which are filled with a softer variety of carbon, will greatly decrease the shifting, since the carbon vapor is formed in greater quantities over the carbon at the core, and thus tends, to a great extent, to maintain the arc in a central position directly between the carbons.

Value of cored carbons on steadiness of voltaic arcs.

Formation of ozone in carbon arc.

During the maintenance of a carbon voltaic arc, a distinct odor is noticeable, especially when the air is moist. This is due to the formation of fairly large quantities of ozone, a modification of the oxygen of the air, due to the passage of the electric discharge through it. The odor is also at times probably due to the formation of small quantities of hydro-cyanic acid. There is also, generally, a small quantity of nitric acid or nitric oxide present. If, however, the E.M.F. between the terminals of the arc is not greater than fifty-five volts, the quantities of the noxious substances that are formed are not sufficient to injure the health. The formation of ozone is advantageous to health, since it acts as a powerful germicide.

Hydrocyanic acid and nitrous oxide sometimes formed.

It is a well-known fact in physics that, when a liquid whose temperature has been raised to its boiling point is being evaporated, it is impossible to raise its temperature beyond that at which the vapor is liberated throughout all parts of its mass. In other words, it is impossible to raise the temperature of a boiling liquid beyond the temperature of its boiling point, provided the vapor is allowed to escape freely into the surrounding air. It is only when the vapor is confined, or is unable to escape, that the temperature rises, because, under these conditions, the pressure on the liquid is increased, and the temperature of its boiling point is correspondingly increased. Any increase in the amount of heat applied to the boiling liquid has no effect on its temperature. It only causes a greater amount of the liquor to be vaporized, that is, it only makes the liquid boil more rapidly.

A boiling liquid whose vapor is allowed to escape into the air can not be raised to a higher temperature than that of its boiling point.

Now, in the formation of the voltaic arc, there is a true volatilization of the carbons, resulting in the production of a temperature that has been estimated as being equal to about 6332° F. This may, therefore, be regarded as the temperature of the boiling point of carbon. Since the point of highest temperature is in the positive crater, it is here that the carbon actually boils, or passes into vapor. It forms, indeed, a veritable caldron. The peculiar hissing noise so characteristic of the carbon arc,

The temperature of the boiling point of carbon.

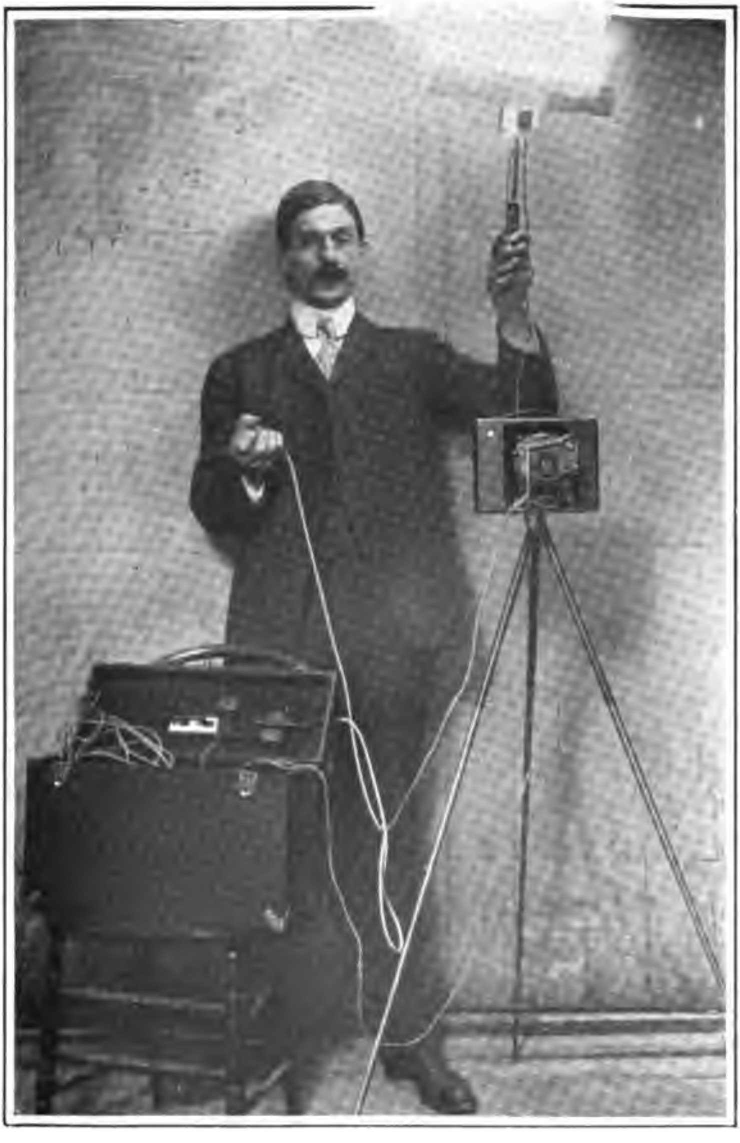
under certain conditions, is believed by some to be due to the actual boiling of the carbon in the crater.

Wanted! for arc light electrodes: a more refractory substance than carbon

The intensity of the light emitted from the carbon voltaic arc, or, indeed, from any body heated to incandescence, increases rapidly with the temperature. In the case of the carbon arc, this limit is reached by the fact that the temperature can not be raised beyond the 6332° F., which is the temperature of the boiling point of carbon. Could some substance be employed instead of carbon, as the electrodes of arc lamps, the temperature of whose boiling point is higher than that of carbon, a greater efficiency would naturally result in the light of the voltaic arc. It does not seem probable, however, that this substance will ever be found, since of all the substances with which we are acquainted, carbon is the most refractory, that is, has its boiling point at the highest temperature. For instance, iridium, a rare metallic substance, which is, probably, the next most refractory substance to carbon, boils at a temperature about one-half that of carbon, while the boiling points of platinum, iron and palladium are even less than that of iridium. It would not appear, therefore, that much improvement can be looked for in this direction, unless it would be in some means for preventing the escape of the carbon vapor, and thus raising the temperature of the boiling point by the increase of pressure. Or, what would amount to the same thing, burning the carbons under suitable conditions in atmospheres of inert gas, under extremely high pressures.

Effect on carbon arc of increasing current strength.

It is the amount of current that passes between the carbons which determines the amount of carbon that is vaporized in order to form the arc. In other words, the volume of the arc will increase with the



ELECTRIC FLASH LAMP FOR PHOTOGRAPHERS

Upon pressing the bulb, with the Prosch lamp, the camera shutter is opened and simultaneously an electric circuit is completed, by which a flash powder in the lamp is ignited. By electric ignition widely separated lamps may be flashed together

volume of the current passing between the carbons, since, of course, any increase in the amount of current passing will necessarily result in the formation of a greater quantity of carbon vapor. No increase of current, however, can increase the temperature, since this is fixed by the temperature of the boiling point of carbon. If the arc has an opportunity to spread laterally, however, the increase of current is attended by an increase in the area of cross-section of the mass of glowing vapor that constitutes the arc proper. Consequently, an increase of current strength will cause a decrease in the resistance of the arc. This is unlike the case of any other conductor conveying an electric current, and arises from the fact that the current may determine the area of cross-section of the conductor, and, therefore, its resistance. For this reason, Ohm's law is inapplicable to the case of a circuit in which a carbon arc is included.

Temperature of the carbon voltaic arc the highest known artificial temperature.

The ordinary carbon arc requires, for its proper maintenance, a current of about ten ampères, and a pressure of about forty-five volts between the carbons. In other words, it requires about 450 watts to maintain it, or in the neighborhood of a half a kilowatt. Since this energy is employed in raising the temperature of the small amount of carbon vapor that constitutes the arc, and as this is a material which posseses a fairly high electric resistance, it follows that the liberation of this energy in this small space results in a high temperature; viz., that of the boiling point of carbon already referred to. This temperature is the highest artificial temperature that man has yet been able to reach, and, as we shall see in discussing the subject of electric furnaces, is employed for various processes in the arts that require high temperatures.

Deposition of graphite on surface of negative electrode.

The surface of the negative electrode is much cooler than that of the positive electrode. Indeed, it is sufficiently cool to permit the highly heated glowing carbon vapor to be condensed in a solid form on its surface. This deposition occurs at that part of the negative electrode which faces the positive crater, and the deposited carbon, when its deposition is sufficiently rapid, takes the shape of the hillock or nipple before referred to, as forming on that part of the end of the negative carbon which lies directly opposite the crater. The carbon so deposited has undergone a change in its physical properties, whereby it is converted into that peculiar modification of carbon known in the arts as graphite or plumbago. This material is employed in the manufacture of lead pencils, and consists of a peculiar modification of pure carbon, so soft that it will readily make marks on paper.

Baking action of intense heat of positive crater on nipple of negative carbon

Before their use in the arc lamps, the carbon pencils or electrodes are incapable of making any mark on paper, but after they have been employed for a short time, it will be found that the negative carbon, which can be easily recognized by a little hillock of carbon on its end, is capable of being readily employed for some time as a lead pencil. This change of carbon into graphite is especially well marked on that part of the negative carbon which has been exposed to the baking action due to the intense heat of the positive crater. Here the carbon, condensed from the carbon vapor, is changed by the intense heat into graphite. Consequently, the nipple, which lies immediately under the crater, shows this change in the most marked manner. The positive carbon in the immediate neighborhood of the crater will be found to possess some graphite, although less than that found on the negative carbon.

During the maintenance of the carbon arc, both carbons gradually waste away, or are consumed. When employed as in the ordinary arc lamp, with the positive carbon directly over the negative carbon, the positive carbon consumes about twice as rapidly as the negative. This arises from the fact that it is the positive carbon which is the sole source of the carbon vapor, and that this carbon, like the negative, is also wasted by gradual oxidation by the air. Again, being placed above the negative carbon, it is subject to mechanical wearing by the action of air currents. Where the carbons are exposed to the air, the consumption of the negative carbon, as we have seen, is entirely due to its gradual oxidation. When the carbons are placed in the ordinary arc lamp, and the same area of cross-section is employed for the positive and the negative carbons, it is customary to employ a length of negative carbon equal to but about one-half that of the positive.

Consumption of positive carbon in continuous-current arcs about twice as great as that of the negative carbon.

As long as the carbons are maintained at the proper distance apart, and are supplied with a current of constant strength, the arc will burn quietly. If, however, these conditions are not maintained, various noises will be heard. Where the distance between the carbons is too small, or where the carbons are so soft that comparatively large quantities of vapor are liberated, hissing sounds will be heard. In such cases the resistance of the arc falls, and the amount of light given off decreases. A disagreeable spluttering noise is often heard, which arises from impurities in the carbon permitting the sudden liberation either of large quantities of carbon vapor, or of the vapors of readily volatilized impurities. Such noises are also sometimes due to the sudden liberation of gases from carbons that have been insufficiently baked.

Hissing sound produced by carbon arc.

Cause of spluttering of arc.

Appearance and cause of the flaming carbon arc.

The value of the carbon voltaic arc as a source of light is decreased by the formation of what is called a flaming arc. This occurs whenever the arc, for any reason, becomes too long. A flaming arc is characterized by a flame from the arc proper extending upward for some distance along the sides of the positive carbon. In such cases the resistance of the arc decreases, and the light emitted is thereby lessened. The flaming arc is either due to the lamp mechanism maintaining too long an arc between the carbons, or to impurities in the carbon, permitting the formation of too great quantities of vaporized matter. It may also be due to soft or imperfectly baked carbons.

Counter E.M.F. of carbon arc.

During the maintenance of the carbon voltaic arc, an E.M.F. is set up between the carbons, in the opposite direction to that required to form the arc. Since this E.M.F. opposes the passage of the current, it is called a counter E.M.F. The resistance of the ordinary carbon voltaic arc is, generally speaking, about five ohms to the inch. An arc, therefore, of say one-eighth of an inch in length, a common length in this country, would have a resistance of about five-eighths of an ohm. The current strength is approximately ten ampères, and the value of the counter E.M.F. is, approximately, from thirty-five to thirty-nine and one-half volts. This value, added to the six and one-quarter volts representing the drop of voltage caused by ten ampères passing against an ohmic resistance of five-eighths of an ohm, represents the value of the voltage that must be maintained between the carbons in order to sustain the arc.

The cause of the counter E.M.F. thus produced is not certainly known. It is possibly due to several different causes, or, most probably, there are several distinct and separate counter E.M.F.'s produced. One of these is, probably, due to the volatilization of carbon in the positive crater; another, possibly, to a thermo-electric effect produced at the positive carbon; and possibly still another to a similar thermo-electric effect produced at the negative carbon. The value of the counter E.M.F. set up in a carbon voltaic arc will vary with the character of the carbons employed. Anything that tends to raise the boiling point of the carbon tends to increase the total E.M.F. required to sustain the arc; while anything which tends to decrease the temperature of the boiling point, tends to decrease the value of such E.M.F.

Probable causes of the C. E.M.F.'s of the carbon voltaic arc.

Houston and Kennelly, in their work entitled "Electric Arc Lighting," thus refer to this subject:

"A very short arc has comparatively little room to spread, owing to the edges of the crater, and, consequently, such an arc can not greatly decrease its resistance by lateral spreading. On the contrary, a long arc has abundant room for lateral spreading, and its resistance is capable of being markedly diminished by an increase in current strength. In view of the preceding principles we arrive at the two following laws:

"1. If the current strength passing through a carbon arc be maintained constant, the pressure at the terminals of the arc is always increased by increasing the distance between the carbons; or, in other words, the apparent resistance of the arc will always be increased by an increase in its length, although said increase may not be exactly proportional to the length, owing to the tendency to lateral spreading.

Houston and Kennelly on the resistance and the C.E.M.F. of the carbon voltaic arc.

"2. If the distance between the carbons be maintained constant, and the current through the arc be increased, then the apparent resistance of the arc may either increase or diminish. It will usually increase when the arc is very short, that is to say, when there is very little room for lateral spreading. Between these two conditions there will be a certain length of arc, at which the lateral spreading will diminish the resistance as fast as the current increases; or, in other words, when the pressure at the terminals of the lamp will be constant for a wide range of current at all current strengths.

"From the preceding, it will appear that the C.E.M.F. of the arc constitutes a much greater part of the total E.M.F. maintained at its terminals than that required to overcome the mere *ohmic resistance,* that is, resistance due to the character of the carbon vapor forming the arc, its length and areas of cross-section."

Why short carbon arcs are no longer commercially employed.

When the length of the carbon arc is decreased too much, say to the length of from one-fiftieth to the one-twenty-fifth of an inch, smaller voltages but greater current strengths are employed. For example, while but twenty-five volts is employed between the carbons, a current of from eighteen to twenty ampères is required in such arcs. Short arcs of this character were employed in the early days of electric lighting, in order to increase the number of series-connected arcs that could be maintained by a dynamo on a given voltage. The increased current strength, however, which, as will be observed, is nearly double that required in the ordinary arc, caused too rapid a consumption of the carbon electrodes; while the short arcs produce the disagreeable hissing noises before referred to. These difficulties have, consequently, led to the general abandonment of short arcs.

When an alternating current is passed between carbon electrodes, so as to form an arc between them, a bright arc is obtained, which is extensively employed to-day for arc lighting. Alternating-current arcs, however, differ from constant-current arcs in that, while in the case of the constant current the arc forms a continuous flame, in the alternating-current arc it is necessarily lighted and extinguished at every reversal of the current. Both carbons have a small crater at their ends. Consequently, there are alternations of light and darkness. But if these follow one another with sufficient rapidity, the light will appear to be steady and constant. In order to thus become constant, these alternate lightings and extinguishments of the arc must follow one another more rapidly than 100 times per second; or, in other words, the alternating current must have a frequency of something greater than 50 periods per second. In practice, it has been found that at 60 periods per second the light is quite steady. Indeed, at 50 periods per second, few eyes can distinguish any flickering in the light.

Alternating-current carbon arcs

Alternating-current arcs successively extinguished and relighted.

It may, perhaps, appear strange that, with a properly operated arc-lamp mechanism, provided the alternations are sufficiently rapid, the steadiness of the alternating-current arc is even greater than that of the continuous-current arc. The reason, however, is evident. In the alternating-current arc the alternate extinguishments and relightings follow one another with great regularity and so rapidly as to produce a light of marked average steadiness; while, in the case of the constant-current arc, the irregular variations, due to the travelling of the arc, or to other causes, may produce differences in its intensity that will cause a marked flickering of the light.

Why an alternating-current arc may give a steadier light than a continuous-current arc.

Current and pressure required for alternating-current arc.

The alternating-current arc requires, generally speaking, when maintained in open globes, a current of about 15 ampères, at a pressure of from 30 to 35 volts. In order to prevent the extinguishment of the light on the change in the direction of the current, the presence of a sufficient quantity of glowing carbon vapor between the arc must be ensured. Consequently, the current strength employed is greater than in the continuous-current arcs. For the same reason, cored carbons are always employed, in order to permit the ready formation of a sufficient quantity of carbon vapor. The power factor of an alternating-current arc, maintained in open globes, is about eighty-five per cent of the apparent watts.

Stronger currents and cored carbon necessary in alternating-current arcs

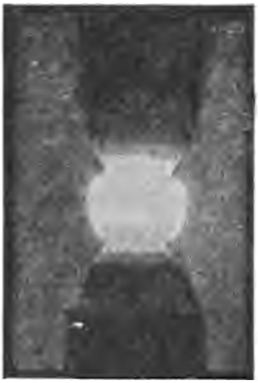


FIG. 70.—Alternating-current Carbon Arc. **Note here that the ends of both carbons are flattened, differing in this respect from the direct-current carbon arc represented in Fig. 69.**

Humming of alternating-current arcs.

A humming sound always accompanies the use of the alternating-current arc. The variations in the current strength, that occur during each alternation, set up corresponding vibrations in the air surrounding the arc, and these produce a more or less musical tone, corresponding in pitch to the number of alternations per second. The general appearance of an alternating-current arc is seen in Fig. 70.

CHAPTER IX

LIGHT AND ILLUMINATION

"Doth make the night joint-laborer with the day."—*Hamlet,* Act I, Scene I

THERE are two distinct ways in which we may regard the artificial light emitted by any source, such, for example, as a candle, gas light, or electric arc lamp; viz., as regards its ability to permit us to distinguish the outlines or shape of a body in an otherwise dark place, and as regards its ability to permit us to distinguish the true colors of the object so lighted up or illumined.

Two necessary properties of artificial illumination.

The ability of an artificial source of light to enable the outlines of an illumined body to be clearly distinguished depends on the amount of light the luminous body emits, or on what is generally called its luminous intensity or candle-power. By the candle-power of a luminous source is meant the intensity of the source expressed in some unit of luminous intensity. A very convenient unit of luminous intensity is that equal to the intensity of the light emitted by a candle of a certain composition and definite size, and burning at the rate of two grains per minute. If, therefore, we speak of a source of light as having a luminous intensity of say 1,000 standard candles per minute, we mean that such a light, if it were possible to reduce it to a mere point, would have an intensity equal to that of 1,000 standard candles concentrated at a single point.

Luminous intensity or candle-power of luminous source.

The standard candle

Flux or flow of light

The light emitted by a luminous source may be regarded as the result of a flux or flow. Just as in the case of the north-seeking magnetic pole, in which a certain quantity of magnetic flux emerges, so a lighted candle may be regarded as having a flux or flow of light. Anything which increases the luminous intensity of a source of light, *i.e.* that increases its candle-power, increases the amount of its flux or flow. Consequently, with an increase in the candle-power or intensity of a luminous source, there is a corresponding increase in the total quantity of light that falls on or illumines the surface of bodies whose outlines and shapes are to be rendered visible to the eye.

Candle-power and illumination.

Care must be taken to distinguish between the words light and illumination. The word light signifies a simple flux or flow emitted by a luminous source, while the word illumination is the quantity of light per unit of area received by the body whose outlines and shapes are to be rendered visible. The light received by the illumined body may come directly from the luminous source, or it may first fall on the surfaces of surrounding bodies, such as the walls, ceiling and floor of a room, and from them be thrown on the surfaces of the body to be illumined.

Difference between light and illumination.

It would seem to be an easy matter to obtain a suitable standard of luminous intensity. It would appear only necessary to light a standard candle and compare the intensity of the light it emits with that emitted by the body whose luminous intensity is to be measured. This simplicity, however, is only apparent. Unless the candle is kept burning at a steady rate, so that only a quantity of two grains of wax or other material shall be consumed per

Standards of luminous intensity.

minute, the amount of light emitted will vary greatly. Now this is not as easy as might be believed. The light increases with an increase in the length of the wick. It will vary if a draught or current of air blow in the room; it will vary with the temperature of the room; it will vary markedly from time to time with the chemical composition of the wax employed, which differs in spots in the candle; and it will vary with a great many other circumstances; so that its candle-power will change from time to time. Consequently, a great variety of other luminous sources have been adopted in different parts of the world.

Some circumstances that affect reliability of standard candle.

If an illumined object received its light directly from the luminous source, it would be possible to determine the value of the illumination by a simple calculation based on its distance from the luminous source; for, it is evident that the intensity of the illumination received from a point source, that is, a source whose light is practically all concentrated in a single point, must be inversely as the square of its distance from the luminous source. Thus, let the light of the candle L, Fig. 71, fall on the surface of a screen placed at A B, at a distance of say one inch from the candle. Then a certain illumination will be received by the screen. If, now, the screen be removed to a distance twice as great from the candle, as, for example, to C D, the same quantity of light

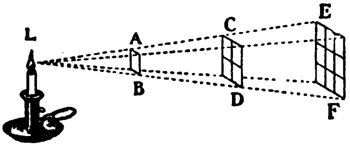


FIG. 71.—Law of Inverse Squares as applied to the intensity of illumination received directly from a point source of light.

from the candle will now fall on or illumine an area four times greater than at A B. Consequently, only one-fourth of the light will be received by an area equal to A B, and the intensity of its illumination will only be one-quarter as great as in the first instance. If the screen be removed to E F, a distance three times as great as at A B, the same quantity of light will now illumine an area nine times as great as at A B, and only one-ninth of the light emitted by the luminous source will be received by an area A B. Consequently, the intensity of its illumination will be but one-ninth at E F what it was at A B. This variation in the intensity of the illumination at different distances is sometimes called the law of inverse squares. In point of fact, however, in nearly all cases, bodies that are illumined from artificial sources of light receive a part of their illumination indirectly by the reflection of the light from surrounding bodies. The law of the inverse squares we have just described is only true when the luminous source is a point, and when the illumined body only receives the light directly from the luminous source.

Law of inverse squares.

The relative intensities of various sources of light can be measured by means of an instrument called the photometer. One of the simplest forms of photometers, shown in Fig. 72, is so arranged as to measure the intensity of the light emitted by a lamp as compared with the light emitted by a candle. An upright rod of some opaque substance, such as wood, is placed in front of a screen, so that the shadows of a lamp and a candle respectively may fall side by side on the surface of the screen, the position of the candle being fixed, and the lamp being moved from or toward the screen until the two shadows appear to be of the same density. The relative

Principle of operation of the shadow photometer

luminous intensities of the candle and the lamp will then be proportional to the squares of their distances from the screen. Suppose, for example, that the lamp requires to be moved twice as far from the screen as the distance of the candle before the two shadows appear of the same density. Then the luminous intensity of the lamp will be four times as great as the luminous intensity of the candle.

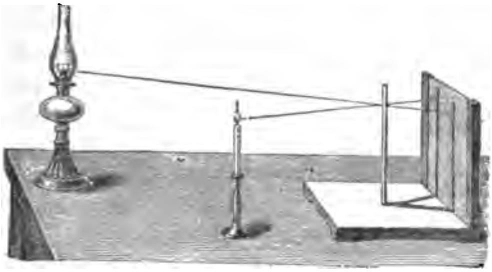


FIG. 72.—The Shadow Photometer. Note the relative distances at which the candle and the lamp are able equally to illumine each other's shadow of the rod.

A better form of photometer, called, from the name of its inventor, the Bunsen photometer, consists of a screen of paper S, Fig. 73, placed in a vertical position between the two sources of light whose luminous intensities are to be measured; for example, a gas burner B and a candle flame A. The

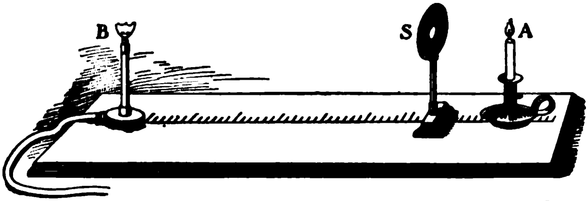


FIG. 73.—Bunsen's Photometer. Note the fact that the gas flame B, although much further from the paper screen S, is able to send an equal amount of light through the grease spot in the centre of the screen as the candle flame at A, which is much nearer the screen.

Principle of action of Bunsen's photometer paper screen has a spot of grease placed at its centre, so as to permit the light to pass through this part of the screen. If this screen be so placed that it receives a greater illumination from one of the lights than the other, as, for example, from the gas burner, then, on the side of the screen nearest the candle the central part of the disk will appear to be brighter than on the opposite side, for a greater quantity of light from the gas burner passes through the grease spot than falls on the ungreased side of the screen nearest the candle flame. If, however, the screen be moved to such a point between the two sources of light that both sides of the disk are equally illumined, the grease spot will disappear, for, in this position, its opposite faces are receiving an equal illumination from the two sources, and the intensities of the two sources of light will, therefore, be directly proportional to the square of their distances from the screen. If, for example, as is represented in Fig. 72, the distance be as 4 is to 1, that is, if the gas flame is able to illumine the surface of the disk to an extent equal to that of the candle, then the intensity of its light will be 16 times that of the candle.

The ability of an artificial light to enable the eye to distinguish the colors of the bodies it illumines as distinctly as would daylight; or, in other words, to give them what might be called their true sunlight or daylight color-values, depends on the character of the light they emit. If a narrow slice of sunlight be passed into a dark room through a hole in a shutter, and is then caused to pass through a glass prism P, Fig. 74, the light will be separated into a number of different colored rays. If these rays be permitted to fall on a screen, they will be separated into a brightly colored band VR called the spec-

Composition of sunlight shown by prism of glass.

trum. Here only a few of the colors of the spectrum are represented by their initial letters; viz., violet, indigo, blue, green, yellow, orange, and red. Sunlight consists of a very great number of different colors. Now, when sunlight falls on different colored objects, certain of these rays are absorbed, and only those corresponding to the particular color of the body are given off. It is in this way that the color of bodies is recognized through the agency of the eye.

Some artificial sources of light contain certain of these colors only. Some sources of light contain a preponderance of certain colors only. For example, they are rich in the red, orange and yellow tints, while the blue, the indigo and the violet rays are either entirely absent, or exist but in very small quantities. Necessarily, therefore, when such artificial light falls on colored bodies that would appear blue, indigo or violet by sunlight, their true color

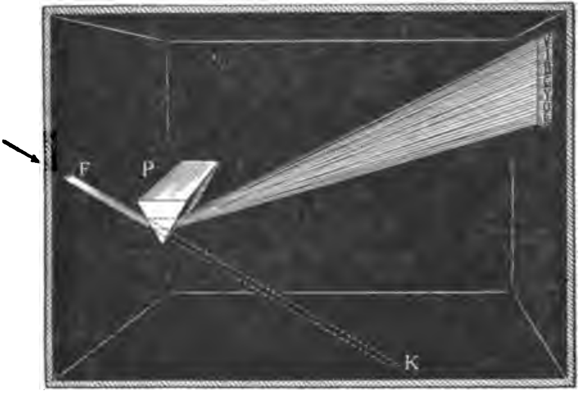


Fig. 74.—Spectrum of Daylight formed by passage of light through a prism. Note the fact that the different colored rays are differently refracted or bent from their course, FK, the violet being the most and the red the least refracted.

Deficiency of certain artificial lights in sunlight values.

values can not be perceived by the eye. The nearer the approach of artificial light in these various rays to the proportions of the different colored rays that exist in sunlight or in daylight, the nearer can such light give to the objects it illumines their true daylight or sunlight-values. The light emitted by an arc lamp corresponds fairly closely in its composition to that of sunlight. The light emitted by the ordinary incandescent lamp is deficient in some of the colors or tints near the violet end of the spectrum.

Various sources of the light of the carbon voltaic arc.

The principal source of the light produced by a continuous-current carbon voltaic arc is the tiny crater in the positive carbon. According to Crocker, where the carbons are placed directly one above the other with the positive carbon above, if we represent the total intensity of light emitted by one hundred parts, then some eighty-five of such parts, or eighty-five per cent, would be emitted by the positive crater, about five parts, or five per cent, would be emitted by the arc proper, and the remaining fifteen parts, or fifteen per cent, by the negative carbon. Necessarily, therefore, the greater proportion of light emitted by a carbon arc must be thrown downward.

Distribution of light of continuous-current carbon voltaic arc.

The various amounts of light emitted by such carbon arcs in different directions will depend on the character of the carbons employed, as well as on the distance that separates them. Generally speaking, however, in continuous-current arcs the distribution of the light will be that represented in Fig. 75. Here, as will be seen, but little light is thrown above the horizontal plane passing through the carbon arc. No light whatever passes vertically upward, and by far the greater intensity of the light emitted is given off in a direction about 45° below the horizontal line. The relative proportions of the light emitted in various directions around the arc can be obtained by drawing straight lines from the arc to different parts of the curved line. If the candle-power of the arc represented in this figure be 2,000 standard candles, in the direction OC or OF, of maximum intensity, then, probably, only about 220 candles would be emitted in the direction of the horizontal plane, and, probably, only some 200 candles in the upward directions OA or OH.

Since, in the alternating-current arc, the upper and lower carbons are alternately positive and negative, a small crater is established in each, so that the distribution of the light must differ considerably from that in the continuous-current arc. In alternating-current arcs, therefore, as we should expect, the distribution of light above the horizontal plane is very nearly equal to that below such plane. For all purposes such as street lighting, or other locations where the light is desired mainly below the lamp, in order to avoid the loss of that portion which is emitted in the direction above the horizontal plane, a reflector, usually in the shape of a

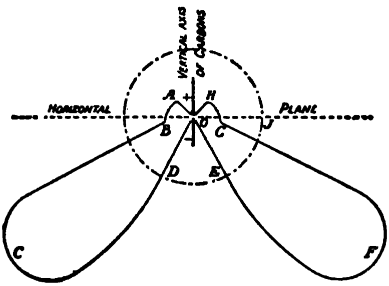


FIG. 75.—Curves Showing Distribution of Light of Continuous-current Carbon Voltaic Arc. Note that nearly all the light is thrown downward at an angle of 45° from the horizontal plane or in the direction GF or BC.

Distribution of light of alternating-current carbon voltaic arc.

porcelain shade, is always placed above the carbon. In alternating-current arcs, as in continuous-current arcs, the distribution of the light varies with the quality and the size of the carbons, and with the length of the arc. The distribution, however, is, as a rule, fairly represented by the curves shown in Fig. 76.

It will, clearly, be impossible fairly to determine the total intensity of the light emitted by any carbon arc by measuring it with a photometer, in any one direction only. In practice, the candle-power is generally measured in four different ways; viz., an average is taken of many separate measurements in a horizontal plane. The average of these is called the mean horizontal candle-power; or, measurements are taken of the intensity of the light in all directions and at all angles, both above and below the horizontal, as well as in the horizontal plane. The average of these measurements is called the mean spherical candle-power; or, measurements are taken,

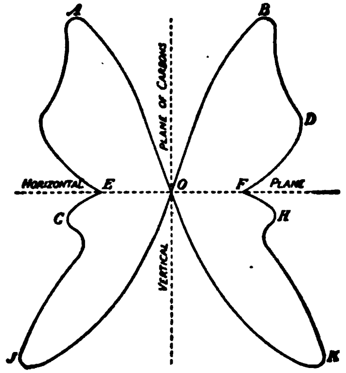


FIG. 76.—Curves Showing Distribution of Light of Alternating-current Carbon Arc. Compare the distribution of the light in this case with that of the continuous-current arc in Fig. 75.

Mean horizontal candle-power.

Mean spherical candle-power.

in a similar manner, in various directions below the horizontal plane only. The average of these measurements is called the mean hemispherical candle-power; or, a measurement is taken in the direction of the greatest candle-power. This is called the maximum candle-power.

Mean hemispherical candle-power.

Maximum candle-power.

It is by no means an easy matter properly to determine the candle-power of an arc lamp. The total quantity of light emitted by the arc varies greatly from time to time, so that a careful measurement taken at any moment, in any direction, may be either above or below the average intensity in that direction. Moreover, the travelling, or shifting, of the arc, causes a still greater irregularity in the intensity of the light emitted in different directions. Clearly, the fairest estimate of the light emitted would be the mean spherical candle-power. But this, unfortunately, is most difficult correctly to determine. For street lighting the mean hemispherical candle-power is most important. These difficulties in properly measuring the candle-power have led to the general adoption of what is called the nominal candle-power; *i.e.*, a candle-power determined not by photometric measurements, but calculated from the number of watts present in the arc under certain conditions. For example, it is assumed that a carbon arc produced by a current of 10 ampères, at a pressure of 45 volts, or at 450 watts, has a photometric intensity of 2,000 nominal candles. It must not be supposed, however, that we will obtain 2,000 nominal candles from any 450 watts lamp, since these particular 450 watts must be obtained from the 10 ampères, and the 45 volts before referred to. A small change either in the value of the current, or of the pressure, will produce a marked difference in the candle-power of the arc.

Difficulty in measuring candle-power of arc light.

Nominal candle-power.

450-watt arc or 2,000 nominal candle-power.

Area of crater and total intensity of light.

Any increase in the current strength that maintains a carbon arc, results, as we have already seen, only in an increase in the quantity of carbon vapor that is given off; or, in other words, it results in an increase in the area of the crater in the positive carbon. Since this crater is the principal source of light, the nominal candle-power of the arc can be, approximately, determined from the area of the crater. It has been estimated, for example, that the crater emits, approximately, 100,000 candles for every square inch of surface. This would make the crater of a 2,000 candle-power lamp have an area of about one-fiftieth of a square inch.

Arc-light sunburns.

The intensity of the light of the carbon arc is so great that care must be taken not unnecessarily to expose the eyes to its light; otherwise, serious inflammation of the eyes may result. Like sunlight, a continued exposure to an arc light produces painful burns, like sunburns.

Actinic or photographic power of arc light.

Since the light emitted by the carbon voltaic arc is rich in the colored rays near the violet end of the spectrum, it is, like sunlight, suitable for photographic purposes; that is to say, the actinic power of the arc light, or its power of producing such chemical decompositions as are necessary in order to obtain photographic pictures, is comparatively great. Consequently, arc-light mechanisms are employed, as we shall shortly see, for general photographic purposes.

CHAPTER X

SOME EARLY ATTEMPTS AT ARC LIGHTING

> "The dazzling brilliancy of the light, first investigated by Davy with two thousand cells early in the century, has long led philosophers and engineers to endeavor to utilize it for purposes of illumination."—PREECE-NOAD

SHORTLY after the exhibition, by Davy, of the splendors of the light of the carbon voltaic arc, various attempts were made to produce lamp mechanism, by means of which the carbons could be maintained at such a constant distance apart as was necessary to produce light of the steadiness required for purposes of artificial illumination. Two serious difficulties, however, were soon experienced. In the first place, although the voltaic battery, as given to the world by Volta, was an immense improvement on all previously existing electric sources, yet the current it produced lacked the steadiness necessary for commercial arc lighting. Then, in the next place, a difficulty arose from the fact that the carbons generally employed in arc lighting were either formed from pieces of well-burned charcoal, or consisted of short lengths, sawn from the mass of artificial carbon, deposited on the inside of the retorts employed for the production of illuminating gas, by heating coal to high temperatures in inclosed spaces.

Current of voltaic battery not sufficiently steady for arc lighting

Charcoal, or gas-retort carbon, unsuited for commercial arc lighting.

In 1840, Bunsen made a great improvement in the voltaic battery by substituting a cheaper material, Bunsen's voltaic battery.

i.e. carbon, for the expensive platinum of the Grove double-fluid battery. Since double-fluid batteries possess a far smaller polarization than ordinary batteries, Bunsen's invention, first producing a cheap double-fluid battery, may be considered as marking an era in the history of arc lighting, since it furnished an electric source capable of producing a much steadier current than had heretofore been possible. Moreover, the resistance of the battery was comparatively small, so that it yielded a strong current.

Bunsen's artificial carbons.

But Bunsen did more for the advance of arc lighting than simply improving Grove's battery. In order to obtain the carbon plates necessary for his voltaic cell, he formed them artificially, in the shape of plates and rods, by thoroughly mixing various kinds of finely powdered carbon into a paste, with liquids, such as molasses or tar, that were capable of being carbonized, that is, of leaving a deposit of hard carbon when exposed to high temperatures while out of contact with the air. These mixtures of carbonaceous powders and carbonizable liquids were subjected to a great pressure, in suitably shaped molds, and subsequently dried and exposed to the prolonged action of heat in an inclosed space, to which air had no access. Under these circumstances, the carbon, deposited by the decomposition of the carbonaceous liquids, served to bind the particles of the powder into a strong coherent mass, which possessed fairly high conducting powers for electricity. Workers in the field of electric lighting were not slow in employing such artificial carbons in place of the pieces of charcoal or gas retort carbons for the electrodes of arc lamps, and this substitution proved of great advantage to the art.

How Bunsen produced his artificial carbons

The impetus thus given to the art of electric lighting resulted in great improvements in the various forms of arc-lamp mechanisms. In order to be able to understand these improvements more fully, let us briefly examine some of the conditions necessary for maintaining a carbon voltaic arc. In the first place, it is necessary that the carbons be brought together and then gradually separated, so as to form or strike the arc between them. Then, since the carbons are consumed during the maintenance of the arc, some means must be provided, by the movement of either one or both of the carbons, to keep them at a constant distance apart. Moreover, since the positive carbon is consumed more rapidly than the negative carbon, if these movements are imparted to both of the carbons, the movement given to the positive carbon must be more rapid than that given to the negative carbon.

Some conditions necessary for maintaining a carbon arc.

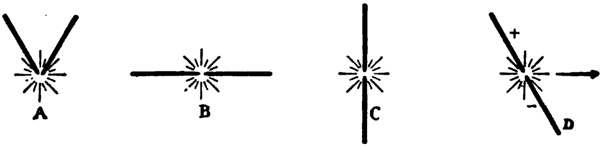


FIG. 77.—Various Arrangements of Arc-light Carbons.

The carbons were given various positions. In some lamps they were placed inclined to one another, with the ends of the carbons pointing generally downward, as shown at A, in Fig. 77. This was done in order to ensure the greatest quantity of light being emitted in a direction below the lamp. In some lamps, the carbons were placed in a horizontal plane, as shown at B; in others they were placed one directly above the other, as at C; and in still others, the two carbons, although placed in the

Various positions given to arc-light carbons.

General position of carbons in ordinary lamps and in search-lights.

same straight line, yet this line, instead of being placed vertically as at C, was placed in an inclined position, as shown at D. Of these various positions, those shown at C and D, are to-day almost invariably employed—the first for all purposes of ordinary lighting, and the second for searchlights, where it is required that the light shall be given off mainly in a horizontal plane.

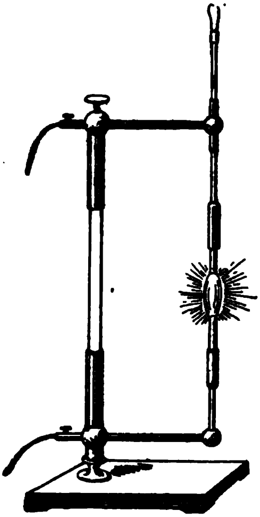
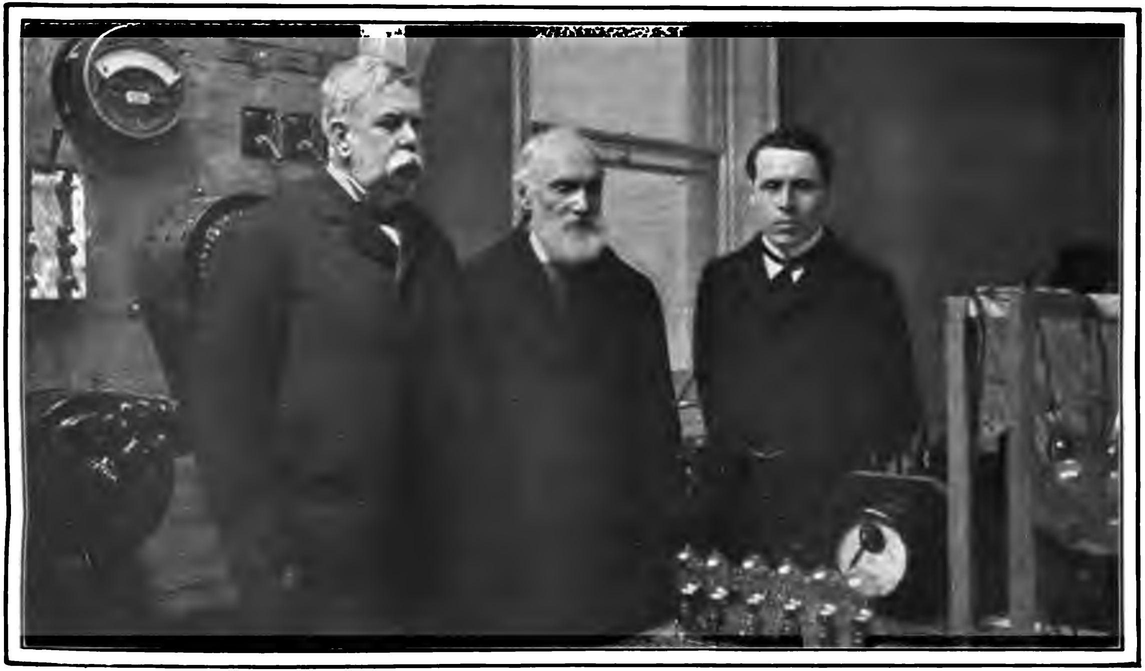


FIG. 78.—Hand Regulator for Carbon Arc Light. Note that here the upper carbon only is moved, being pushed toward the lower carbon when, by consumption of the two carbons, the distance between the two carbons has become too great. In most hand regulators the carbons are moved together by means of a screw.

Hand and automatic arc-light regulators.

The earliest form of arc-light regulator was operated by hand. As soon as the carbons, through consumption, had reached a certain distance apart, the hand of the operator was employed to move them together, as shown in Fig. 78. In all cases where the carbons were placed one directly above the other,



Mr. George Westinghouse Lord Kelvin Mr. Charles Merz

DISTINGUISHED ELECTRICIANS AT A TEST OF THE HEWITT STATIC CONVERTER

The Static Converter, a brilliant invention of Mr. Peter Cooper Hewitt for changing alternating currents into direct currents, is the queerly-shaped glass vessel on the extreme right. This is filled with mercury vapor

the upper carbon only was so moved. Necessarily, an arc-light regulator of such a type would be impossible to employ, except in the lecture room, where but a single light was required, and that only for an hour or so at a time. Automatic regulators, or those in which one or both of the carbons are moved toward and from one another, so as to maintain a constant distance between them, were, however, soon invented.

Early attempts of Deleuil and Archereau at out-door arc lighting

Immediately following the improvements in the Bunsen battery a number of automatic arc-light regulators were invented. These were of a type suitable only for use where but a single lamp was employed in the circuit of the generator. Among such inventions were those of Deleuil and Archereau, who, between the years 1841 and 1844, carried their improvements so far that they were able to maintain arc lights in the open air in Paris. One of these lamps was placed on the Conti dock, and the other on the Place de la Concorde. The arcs were maintained within a partially vacuous glass globe, so as to prevent the carbons from being rapidly consumed by the air. Deleuil and Archereau's experiments created great public excitement, and the belief existed for a while that the problem of successful arc lighting had been solved; but it was soon found that, even with the improved battery of Bunsen, the current could not be produced cheaply enough, or with the steadiness requisite for actual use; so that this effort eventually failed.

Use of arc light at opera of "The Prophet" in 1846.

In 1846, Duboscq, a French philosopher, produced an arc-lamp mechanism which operated so well that its light was employed in the opera of "The Prophet," in Paris, for the purpose of representing the rising sun.

Staite's arc lamps installed on the Liverpool Docks.

Besides the inventors mentioned above, De Moleyns, in 1841, Wright, in 1845, Staite, in 1847, together with numerous others, took out patents in England for improved forms of arc lamps. Of the above, Staite, especially, made a series of careful investigations into the subject, and publicly lighted a large hall in England by means of arc lights. He continued this work until 1852, and his lamps were so much thought of that two were placed on the top of a tower erected for the purpose in the Liverpool Docks. Unfortunately, Staite died during this year, and the experiments were shortly afterward abandoned.

Lacassagne and Thiers's great invention of a two-magnet arc lamp for series circuits.

In 1855, a very important invention was made by two Frenchmen, Lacassagne and Thiers. This invention consisted of a form of regulator which, as we shall shortly explain, permitted more than a single light to be employed on the same circuit. In 1857, by the use of two such arc lamps, Lacassagne and Thiers succeeded, for a short time, in lighting a street in Lyons.

The Alliance magneto-electric generator.

None of the preceding attempts was successful for any length of time, and arc lighting was practically abandoned, until a magneto-electric machine, invented by Nollet, and afterward improved by Van Malderen, offered, for the first time, an electric source capable of producing and maintaining the character of current necessary for arc lighting. This machine, known generally as the Alliance machine, was employed, as early as 1863, for maintaining an electric light in the lighthouse at Havre; and, in 1866, was employed for lighting the yacht of Prince Napoleon.

The Alliance machine was the best of the early dynamo-electric machines, and, as we have seen, was

Description of Alliance machine.

first actually employed in the production of the electric light. The general appearance of the Alliance machine is seen in Fig. 79. It consists of a cast-iron frame, on which are supported 8 series of 5 compound permanent magnets, A, A, A, etc. The armature consists of coils of wire mounted on the surface of a drum, so placed as to be capable of rotation before the magnet poles.

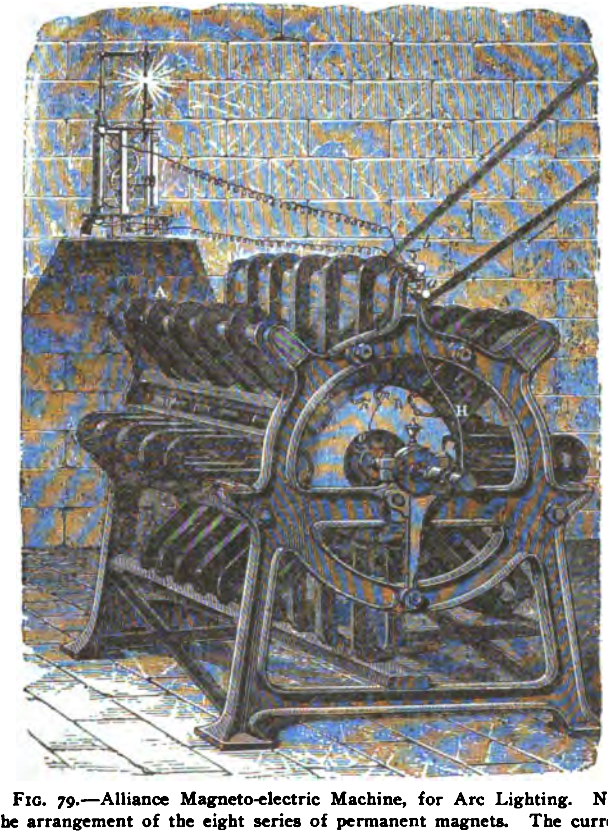


FIG. 79.—Alliance Magneto-electric Machine, for Arc Lighting. Note the arrangement of the eight series of permanent magnets. The current produced by the rotation of the armature is employed to feed the arc lamp shown at the upper left-hand corner of the figure.

The greatest improvement, however, in arc lighting dates from 1870, when Gramme so markedly improved the Pacinnotti machine. In 1876, a Russian, by the name of Jablochkoff, invented a form of arc lamp, which was so simple in its production and application, that it soon came into extensive use in various parts of the world. In the Jablochkoff electric lamp, or, as it is generally called, the electric candle, no attempt was made to feed the carbons toward one another. On the contrary, they were maintained at the same distance apart, being placed side by side and parallel to each other, as shown at the left-hand side of Fig. 80, where the carbons A and B are kept in their relative positions by means of a small quantity of kaolin, which cements them together. In order to strike the arc between the carbons, a small quantity of a carbonaceous material, called the "igniter," was placed between the carbons at their upper ends. The passage of the current through the igniter volatilized it, and thus served to strike the arc. In this lamp, however, if the light became extinguished, it could not be relighted. Consequently, a number of separate candles were generally placed in the same holder, surrounded by a single glass globe, as shown

Jablochkoff's electric candle.

Jablochkoff's igniter.

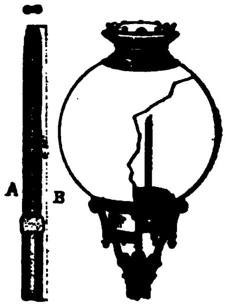


Fig. 80.—Jablochkoff Candle and Enclosing Globe.

at the right-hand side of the figure. In this case the electric connections were so arranged that, when the current failed to pass through one candle, through the extinction of its arc, it was automatically switched over to another candle. Electro-magnetic devices were also subsequently produced to permit the relighting of an extinguished candle, by means of a small piece of carbon that was automatically brought between the carbons, thus re-establishing the arc.

Several separate electric candles placed in a single lamp globe.

Although the Jablochkoff candle was a great improvement, yet serious difficulties arose when it was placed in actual use. At first Jablochkoff employed direct or continuous currents to maintain the arc. Since, however, the positive carbon was consumed about twice as rapidly as the negative, although at the start the carbons were of the same length, yet, after a while, the free end of the positive carbon would be so far below the free end of the negative carbon, that the arc would at last be extinguished. Jablochkoff remedied this difficulty by the use of the alternating current. Other difficulties, however, existed, and eventually led to the replacement of the Jablochkoff system by other systems of arc lighting.

Jablochkoff's candle commercially unsuccessful.

Alglave and Boulard, in their book on "The Arc Light, Its History, Production and Applications," thus refer to the practical application of the Jablochkoff candle.

"For three years the Avenue de l'Opéra has been lighted by electric candles, the large stores have adopted it as a means of advertising, and the large hotels for a sign; it is a feature of all the public *fêtes* in the great cities of Europe as well as in Paris; and to-day there are not less than twenty-five hun-

Alglave and Boulard on the Jablochkoff candle.

dred in use in the two hemispheres, especially in large workshops, railroad stations, public halls and squares, warehouses, theatres, such as the Hippodrome in Paris, and in several places. . . .

Rapid increase in use of the Jablochkoff candle.

"Within four years these wonderful little candles have found means, not only of spreading through France, Belgium, England, and Russia, the country of the inventor, but also have succeeded in penetrating into Greece, Portugal, Brazil, La Plata, Mexico, and even into those places where there would be the least expectation of finding improved machinery, such as the palace of the Shah of Persia, of the King of Cambodia, and the residence of the fierce King of Burmah, who massacred nearly all his family.

Some reasons for failure, commercially, of electric candle.

"Its extended success could not well be greater, although it is far from combining all the qualities indispensable to a good light. The light of the electric candle is fluctuating, and its variations in intensity are magnified by flashes of different colors which often mingle with its light. Those who frequent the Avenue de l'Opéra may have remarked that accidental extinctions, from whatever cause, are sufficiently numerous to render the exclusive employment of the lights of this system in the public service very dangerous. In exhibitions and experiments, where great care has been bestowed upon the establishment and maintenance of the apparatus, they seem to work a little better. But they never have been able to compete with regulators of the best systems, especially differential lamps, not to mention the systems of open-air incandescence which supply also strong centres of light much more agreeable to the eye."

Before the abandonment of the various systems of arc lighting based on the Jablochkoff candle,

Wilde's electric candle.

marked improvements were made on this form of lamp. For example, in 1878, Wilde invented an electric candle in which the two carbons were placed side by side, as in the Jablochkoff candle; but, instead of being insulated from each other by a cementing mass of kaolin, they were separated only by a free air space, as shown in Fig. 81. When no electric current was passing through the candle, the two carbons were permitted to touch each other at their upper ends. On the passage of the electric current, an electro-magnet, placed in the same circuit as the candle, by the attraction of its armature, gradually separated the free ends of the carbons, and thus struck the arc between them. Wilde's candle was a great improvement over the Jablochkoff candle. It burned for a greater length of time, could readily employ longer carbons, and, if acci-

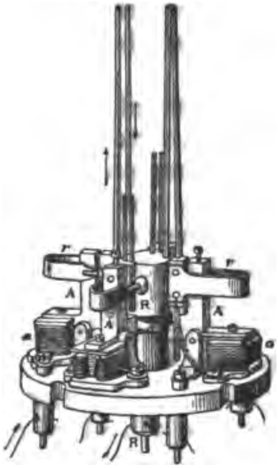


FIG. 81.—Wilde's Electric Candle. Four-candle Holder. Note the direction of the electric current through the two nearly parallel carbons. The carbons being slightly inclined, the arc was maintained at their free extremities, which were nearest together.

dentally extinguished, could be automatically relighted by the current.

Jamin's electric candle.

In 1879, Jamin improved the Wilde candle by surrounding the ends of the carbon by a series of metallic coils, through which the current maintaining the arc was passed. These coils acted, by their attraction on the movable matter of the voltaic arc, to keep it in a central position, and thus improve the steadiness of the arc. Although both the Wilde and the Jamin candles were marked improvements on the Jablochkoff invention, yet they were soon abandoned.

Reynier's semi-incandescent lamp.

A form of lamp intermediate between the arc and the incandescent lamp, which marked a greater departure from the arc lamp proper than did the lamps of Jablochkoff, Wilde, and Jamin, was the semi-incandescent lamp, invented by Reynier, in 1877. The light of semi-incandescent lamps is obtained both from incandescence and from minute voltaic arcs. Like the Jablochkoff lamp, Reynier's lamp was exceedingly simple. A thin rod of carbon, which is made positive, was pressed against a contact piece consisting of a block of carbon. On the passage of the current from the slender positive rod to the contact piece, light was produced both by incandescence and by the arc near the points of contact. As the rod was gradually consumed, it was continuously pushed against the contact piece. The Reynier lamp was modified by Werdermann and others. It has been found in practice that, under the condition of operation of these lamps, the negative carbon is very slightly consumed, the principal consumption being in the positive carbon. In an improved form of Reynier lamp, an additional contact was placed against the positive carbon, near its lower end. The general appearance of a Reynier

Reynier's improved semi-incandescent lamp.

lamp is shown in Fig. 82. Here C, on the left hand side of the figure, represents the positive carbon; B the main contact piece, or negative carbon; L the lateral contact piece. The portion that becomes luminous lies between I and J. A globe is made to surround the carbons, as shown in the right hand side of the figure.

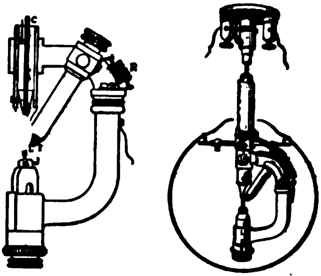


Fig. 82.—Burner and Globe of Reynier's Semi-incandescent Electric Lamp.

Principal parts of Reynier's semi-incandescent electric lamp.

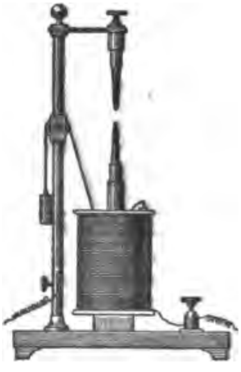


Fig. 83.—Archereau's Solenoidal Arc-light Regulator. The upper carbon was fixed, the lower carbon being maintained in its position by the combined influence of gravity and electro-magnetism.

Before leaving this chapter on "Some Early Attempts at Arc Lighting," it may be well to describe a few of the early forms of lamps.

Archereau's electric lamp.

One of the simplest of these, invented by Archereau, is shown in Fig. 83. Here the upper carbon was fixed and the lower carbon movable. When no current was passing, the lower carbon was brought into contact with the upper carbon by means of a weight, which more than balanced the weight of the lower carbon, together with the iron core on which it was supported. This core was placed inside a solenoidal coil. The current required to maintain the arc was passed through the coils of the solenoid, and, drawing the core within the coil, separated the two carbons and started the arc between them. On the cessation of the current the

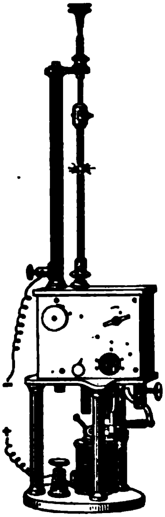


FIG. 84.—Duboscq's Automatic Arc-light Regulator. The carbons were maintained at a constant distance apart by the action of clockwork thrown into action by the electro-magnet shown at the bottom of the figure.

weight again brought the two carbons into contact. This lamp was exceedingly simple, and operated fairly well in circuits where only a single lamp was employed.

Duboscq's arc-light regulator.

Duboscq's regulator, to which we have already alluded in connection with its actual use in the opera of "The Prophet," is shown in Fig. 84. This lamp contained clockwork for the movement of the carbons. As it was employed in the focus of a reflector, it was necessary to keep the position of the arc fixed. Consequently, both carbons were fed or moved toward each other, the movement imparted to the positive carbon being about twice as great as that imparted to the negative. On the passage of the current, an electro-magnet placed at the bottom of the figure, by the attraction of its armature, released a detent, and permitted the wheel-work to move the carbons, under the influence of a driving spring or winding, the hand-key for winding the spring of which is shown in the figure near it.

CHAPTER XI

ARC-LIGHT CIRCUITS AND SOME MODERN ARC LAMPS

> "The time is now come, when activity is required in the matter of street lighting. It has been pointed out over and over again that open arc lighting is too brilliant; the demand is for mild, well diffused light, from a lamp consuming less energy and costing less money. The place to introduce low energy lamps is in the new residential districts, in all the suburbs, and localities where previous illumination has been by gas or oil lamps."—*Arc Lighting:* H. W. HILLMAN

Series and multiple arc-light circuits.

IN arc lighting, as now generally practiced, a number of lamps are employed in the circuit of the generating dynamos. Although these lamps can be arranged in various ways in such circuits, yet there are practically but two methods generally employed; viz., series-arc circuits, and multiple-arc circuits.

Series arc-light circuits.

In series-arc-light circuits, the separate lamps are so placed, in the circuit of the generating dynamo, that the current passes successively through each lamp, as shown in Fig. 85, where the separate lamps, 1, 2, 3, 4, 5, and 6, are so connected to the dynamo D, that the current first passes through lamp 1, then enters lamp 2, and so on, successively, through the remaining lamps, until it leaves lamp 6, and returns to the dynamo. In this manner the positive carbon, as will be observed, will be the upper carbon in all of the lamps.

In actual practice, arc-lamp circuits are sometimes from 15 to 20 miles in length, the electric current passing successively through as many as 100 or more separate lamps. Since each lamp requires a pressure of 45 volts, a total pressure of at least 4,500 volts will be necessary to maintain the arc in the 100 separate lamps, irrespective of the pressure required to overcome the resistance of the line wire in the circuit. Of course, in actual practice the lamps will not be placed near together, as shown in the figure, but at various distances apart, as required to produce the light in the places where it is desired. In a multiple or parallel connection of arc lamps, as shown in Fig. 86, the positive terminals of all the separate lamps are connected to a single positive lead or conductor AA, and, similarly, all the negative terminals are connected to a single negative lead or conductor BB.

High pressures on long series arc-light circuits.

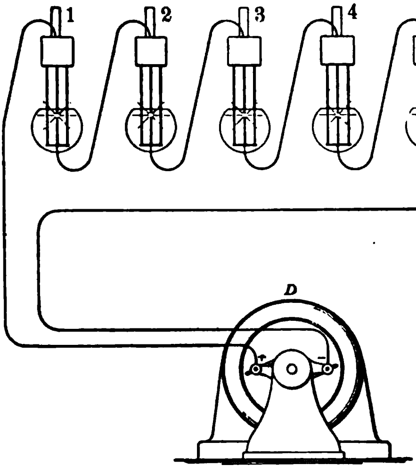


Fig. 85.—Circuit of Six Arc Lights and Dynamo Connected in Series. Note the fact that the connection of the lamps to the positive and negative poles of the dynamo D is such as to render the upper carbons positive and the lower carbons negative.

Multiple-connected arc-light circuits.

As is well known, the current in series circuits

Requirements of series and multiple-connected arc-light circuits.

is of a constant strength in all parts of the circuit. For instance, in the series circuit of 100 arc lamps above referred to, there would require to be maintained, for the proper operation of the arc, a current of a constant strength of about 10 ampères in all parts of the circuit. In a multiple-connected circuit, of say 100 arc lamps, there would require to be maintained a constant pressure of 45 volts between all parts of the positive and negative mains; and, since a current of 10 ampères must flow through each lamp in order to properly maintain it, there would, consequently, be required a total current of 1,000 ampères over the lines or conductors.

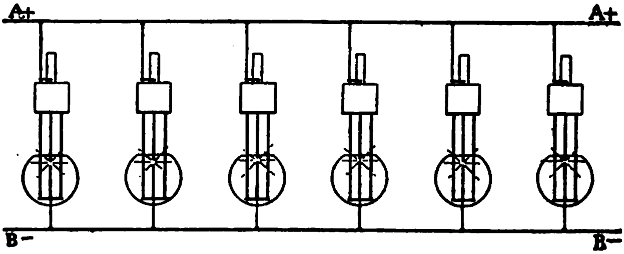


Fig. 86.—Multiple or Parallel Connection of Six Arc Lamps to Constant-potential Mains. The lamp connections are such that all the upper carbons are connected to the positive lead AA, and all the negative carbons to the negative lead BB.

Constant-current, and constant-potential arc-light circuits.

A series-connected circuit is sometimes called a constant-current circuit, because the strength of the current is maintained the same in all parts of the circuit. A multiple-connected circuit is, similarly, sometimes called a constant-potential circuit, because, in such a circuit, the pressure or difference of potential is maintained constant. It will be noticed that, in the constant-current circuit, when additional lamps are introduced, the pressure required at the dynamo terminals is correspondingly increased, while the current strength remains constant. On the contrary, in a constant-potential circuit, for every additional lamp introduced, an increase in the current strength is required, while the difference of potential or pressure remains constant.

A little thought will show that the amount of energy required is the same in the two cases above cited, in which 100 arc lamps are maintained in a constant-current and in a constant-potential circuit. For, in the case of the constant-current circuit, we have a current strength of 10 ampères, maintained at a pressure of 4,500 volts, or 45,000 watts, or 45 K.W. In the constant-potential circuit, we also have a pressure of 45 volts and a current of 1,000 ampères, or, again, 45,000 watts, or 45 K.W.

Energy the same in the preceding constant-current, and constant-potential arc-light circuits.

Although the amount of energy is the same in the constant-current circuit as it is in the constant-potential circuit, yet, with the same loss of energy in the conductors, the weight of the conductors would be very much greater in the case of the constant-potential circuit. In the case of the constant-potential circuit, a current strength of 1,000 ampères, at a pressure of 45 volts, is employed, while, in the constant-current circuit, a current strength of only 10 ampères, at a pressure of 4,500 volts, is employed. The advantages of small current strength and high pressure are all in favor of the constant-current circuit, and permit it to transmit the same amount of energy at no greater loss than would exist, in the case of the constant-potential circuit, with a weight of conductor several thousand times that of the constant-current.

Difference in weight of conductors in low and high current circuits.

Another way of looking at this matter will tend to make clearer some of the advantages of the constant-current distribution of arc lamps over the constant-potential distribution. Generally speaking, the economy of distribution of a constant-current circuit increases with every additional lamp added to the circuit; for, no matter how many lamps are employed, the current strength remains the same, each additional lamp added increasing the pressure required at the dynamo terminals. On the contrary, in the constant-potential distribution, since the pressure at the dynamo terminals remains practically constant, every additional lamp added increases the amount of current the conductors are obliged to transmit. So far as the weight of conductors, therefore, is concerned, the greater the number of lamps on a constant-current circuit the greater will be the pressure at which the energy is transmitted from the dynamo to the lamps, and, consequently, the smaller, proportionally, will be the weight of wire or conductors required to transmit such electric energy. On the contrary, in the constant-potential circuit, each additional lamp added to the circuit, increasing the amount of current that flows, tends to increase the weight of the conductors, and this in a greater proportion than that of the increase of the current itself. Consequently, with a constant-current circuit, considered as a means for the sale, by a central station, of the electric energy required to maintain arc lamps, the profits will, necessarily, be greater in proportion to the amount of business done, that is, the number of lights supplied; while, in the constant-potential circuit, after such circuit has once been installed, the percentage of profit will decrease rapidly as the amount of business increases, a practically impossible condition for carrying on a large business.

Constant-current circuits *vs.* constant-potential circuits.

The excessive cost of such conductor would, of course, not permit the commercial distribution of arc lamps on constant-potential circuits, where the length of such circuits is great. There frequently occur, however, circumstances, such as in the densely built portions of large cities, where a great number of arc lamps are to be employed within comparatively short distances from the centre of distribution, in which constant-potential circuits can be advantageously used. Such, too, is especially the case in many large cities, where constant-potential circuits are already employed underground for the distribution of incandescent lamps. Here it would be more economical to employ a part of the current for the distribution of a few constant-potential arc lights, than it would be to install separate series distribution circuits, when, of course, the pressure employed on the constant-potential mains is not too great, say not over 250 volts. Moreover, arc lamps, when placed on constant-potential circuits, possess so great an advantage in some respects over lamps on constant-series circuits, that the former may sometimes be preferred, even though far costlier to install.

When and why constant-potential circuits are employed for arc-light distribution.

It would not be practicable to employ a lamp with a single electro-magnet, such, for example, as the Archereau lamp, where several such lamps are connected in series. For, should one of such lamps improperly act, as, for example, by sticking and failing to cause one of its carbons to move toward the other carbon, an increase in the resistance of the entire circuit would follow, attended by a decrease in the current strength. All the other lamps would instantly feed their carbons so as to endeavor to maintain the current strength constant; but, as soon as the improperly acting lamp did feed, all the other lamps would instantly feed. In other words, an imperfect action of any single lamp

A single-magnet arc lamp impracticable in a series-connected arc-light circuit.

would cause an irregularity in all the remaining lamps in the circuit, their arcs alternately increasing and decreasing in length, thus producing very disagreeable irregularities in the amount of the light emitted.

Lacassagne and Thiers's doube-magnet lamp suitable for multiple-connected arc-light circuits.

This difficulty is entirely obviated in arc lamp regulators in which two separate electro-magnets are employed to maintain the distance apart between the carbons. We have already alluded to the great invention made by Lacassagne and Thiers in 1885. This invention may be regarded as constituting an era in the history of arc lighting. It consisted in the employment of two separate electro-magnets in the feeding mechanism of the lamp. One of these magnets was placed in the same circuit as that of the arc, and is now generally called the series, or the main-circuit magnet. The other magnet was placed in a shunt or derived circuit around the arc, and is generally called the shunt magnet. The arrangement of the main circuit and shunt magnets in an arc-lamp regulator is shown diagrammatically in Fig. 87, where the series magnet M is placed in series with the arc A, and the shunt magnet S is placed in a shunt or derived circuit around the arc by being connected with the circuit between the points T^1 and T^2. The series magnet M is wound with a few turns of coarse wire, and, therefore, has a small resistance. The shunt magnet S is wound with many turns of fine wire, and, therefore, has a great resistance, sometimes as high as 500 ohms and over. The greater proportion of the current will, therefore, flow through the main circuit or series magnet and the arc, especially when the carbons are in contact. When, however, the carbons are gradually consumed, and the distance between them increases, the resistance in the circuit of the

Current flow through series and shunt magnets in arc lamps.

main-current magnet M increases, and, consequently, a greater proportion of current flows through the coils of the shunt magnet S.

Opposite actions of direct and shunt magnets on motion of carbons.

Although a great variety of shunt-circuit carbon arc lamps have been devised, yet they practically all operate on the same principle. The armature or core of the shunt magnet is so connected with the lamp mechanism that its movement toward and from the magnet poles tends to oppose whatever action is performed by the armature or core of the direct-current magnet. If, for example, as is generally the case, the direct-current magnet acts to separate the carbons, the shunt magnet acts so as to bring them together. Consequently, under the action .of these two opposing forces, the carbons can be maintained at a constant distance apart, and the light of the arc is thus made steady and reliable.

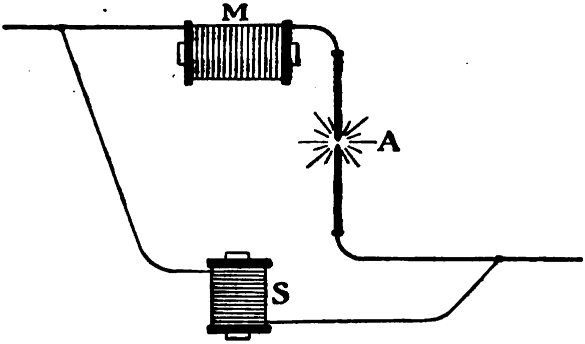


FIG. 87.—Diagrammatic representation of Series and Shunt Magnets of Arc Lamp. Note that as the resistance in the circuit of the series magnet M increases by the consumption of the carbons increasing the distance between them, more current passes through the shunt magnet S, thus enabling it to act on some mechanism that permits the carbons to come together.

Two methods of feeding the carbons are employed. In one a clutch acts directly on the lamp-rod; in the other it acts directly on the carbon itself. Among other advantages possessed by the first method is that the metallic lamp-rod permits of a better contact than does the carbon itself, since the surface resistance of the carbon is often very high. Then, again, the weight of the lamp-rod renders the fall of the carbon more certain. On the other hand, unless the rod is carefully kept clean and polished, its surface resistance increases; moreover, the rod can be easily bent. But the principal objection to its use is in the increase in the length of the lamp. On the other hand, one of the principal objections to feeding the carbons directly arises from the fact that the carbons are comparatively light, so that they do not tend to fall in as positive a manner as is desirable. In order to avoid this difficulty, weights are sometimes added. Another objection to the direct feeding of the carbon is the difficulty of obtaining efficient electric contact. If this is obtained by frictional contacts, difficulties may arise from the liability of arcing occurring, unless the contacts are kept very clean. With direct feeding of the carbons the contact is generally effected by means of flexible cords.

Lamp feeding by lamp rods and by carbons only.

Advantages and disadvantages of lamp clutch gripping lamp rod and carbons

In some forms of shunt arc lamps, the solenoidal coils of the direct and shunt magnets are either provided with the same core, or the armatures of the direct and shunt magnets are connected together by suitable mechanism. This variety of shunt lamp is sometimes called the differential lamp. For example, in the old form of the Thomson-Houston lamp, shown in Fig. 88, the series and shunt magnets are provided with conical-shaped poles, that attract armatures furnished with suitably shaped openings to fit over these poles. These armatures are connected together by being supported on the

Differential arc lamp.

Thomson-Houston arc lamp.

same rocking lever *ab*, pivoted at *a*. A clutch *dc*, operated by the extension *b* of the working lever, is provided at one of its ends with a spring *c*. This clutch is so connected that, when the armature of the series magnet is attracted to the conical magnet

Principal parts of old form of Thomson-Houston arc lamp.

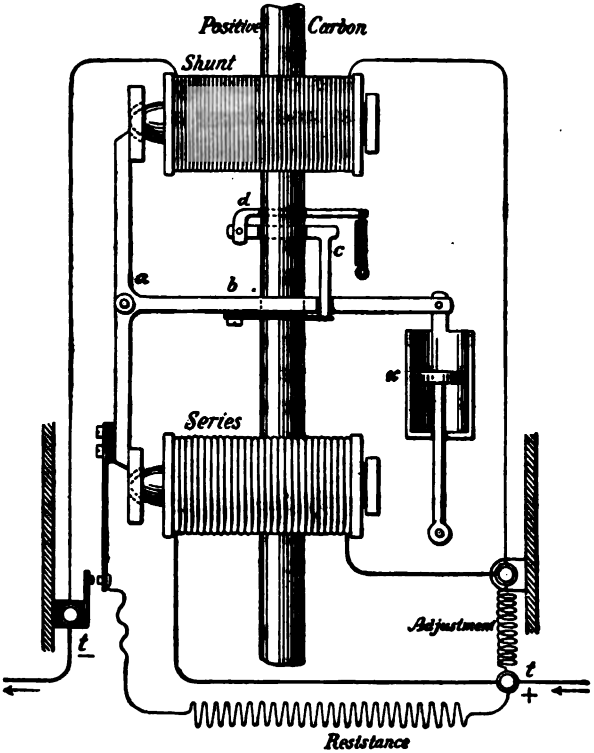


FIG. 88.—Old Form of Thomson-Houston Arc-lamp Mechanism.

pole, the clutch catches or grasps the carbon. When, however, the arc becomes too long, and so increases the resistance of the circuit, the greater current passing through the shunt magnet causes it to attract its armature, to move the clutch in the opposite direction, and so permit the positive carbon to fall or feed

Use of dash pot in lamp. toward the negative carbon. The dash pot, *x*, a cylindrical-shaped vessel filled with oil or water, is provided to prevent too sudden movements of the carbons. This it does by the resistance which is offered by its piston to rapid movements in the cylinder. In all forms of shunt lamps matters are so arranged that, when the carbons are separated the particular distance that will produce the best results in the steadiness of the light, the opposing tendencies of the series and shunt magnets will just balance each other.

Automatic *vs.* hand arc-light regulators. Automatic regulators maintain the required distance between the carbons far more promptly and closely than would be possible by means of a hand regulator, even when operated by the most expert hand; for the electric current itself is capable of judging far more quickly and accurately just when the carbons need adjustment; *i.e.* to be moved toward or from one another, than would be possible for an attendant to judge. Indeed, a well regulated arc lamp will so promptly feed or adjust its carbons that it is often impossible for one to determine that any feeding is taking place.

Automatic cut-out for series-connected arc lamps. In all constant-current arc-lamp circuits it is necessary to employ a device that will afford a continuous path for the current past any lamp that might either fail to properly feed, or whose carbons have been completely consumed. If this is not done in arc-light circuits of this type, where many lamps are connected, an arc of great length may be drawn between the faulty carbons, and damage to the lamp, if not to surrounding property, might result. This need is met by the use of what is called an automatic cut-out for series-connected lamps. Such a device, as shown in Fig. 89, consists of an electro-magnet S, wound with a coil of fine wire that is placed in shunt around the carbon electrodes. When, from any cause, the resistance of the arc becomes too great, as, for example, when the carbon fails to feed, the current strength in the circuit increases until, by the attraction of the armature A of the cut-out magnet S, a spring is permitted to automatically close a short circuit at A, thus cutting the lamp out of the circuit, and, at the same time, providing a path through which the current can flow on to the other lamps.

Method of operation of automatic cut-out.

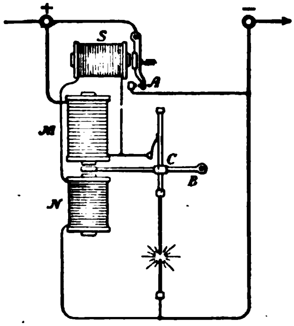


Fig. 89.—Circuit Connections of Automatic Cut-out for Arc Lamp. Note the circuit connections whereby the cut-out magnet S is placed in shunt around the positive and negative carbons.

When arc lamps are employed on constant-potential mains, where the pressure is say 110 volts, it is necessary to insert two lamps in series in the manner shown in Fig. 90. Lamps employed on constant-potential mains in this case are differential lamps, and are provided with a hand-operated switch, which introduces the lamps into the circuit on opening. In the case of series-connected lamps, a similar hand switch is employed, but it operates by closing the circuit past the lamp, thus practically

Hand switch for multiple-connected arc lamp.

Safety fuse, or automatic cut-out for multiple-connected arc lamps.

cutting it out of the circuit. In multiple-connected arc lamps there is generally provided an additional safety device, consisting of a strip of some readily fusible alloy, such as lead, which has a sufficiently great area of cross-section to carry the current generally employed, but which will be fused, and thus automatically open the circuit, on the passage of an unusually strong current. Such a device is called a fuse wire or safety switch.

Where the constant-potential mains have pressures of 250 volts, 4 arc lamps are connected in series across them. Where, as in the case of street railway circuits, 500 volts are employed, 8 or 9 separate lamps are placed in series across the mains. In all such cases, a resistance is placed in the lamp circuit. Generally, this is placed in the body of the lamp, though sometimes outside of it. In all cases where single lamps are employed on constant-potential mains, no cut-out is necessary, since either when the carbons are entirely consumed, or when they cease properly to feed, the lamp is simply cut out from the circuit.

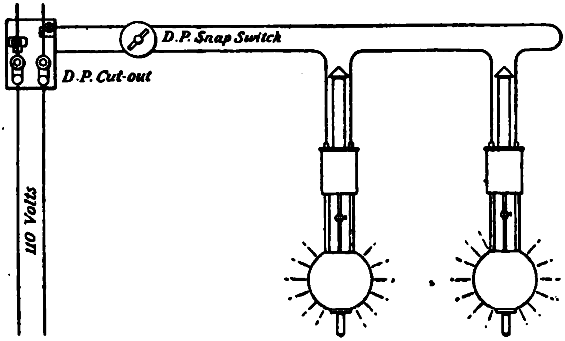
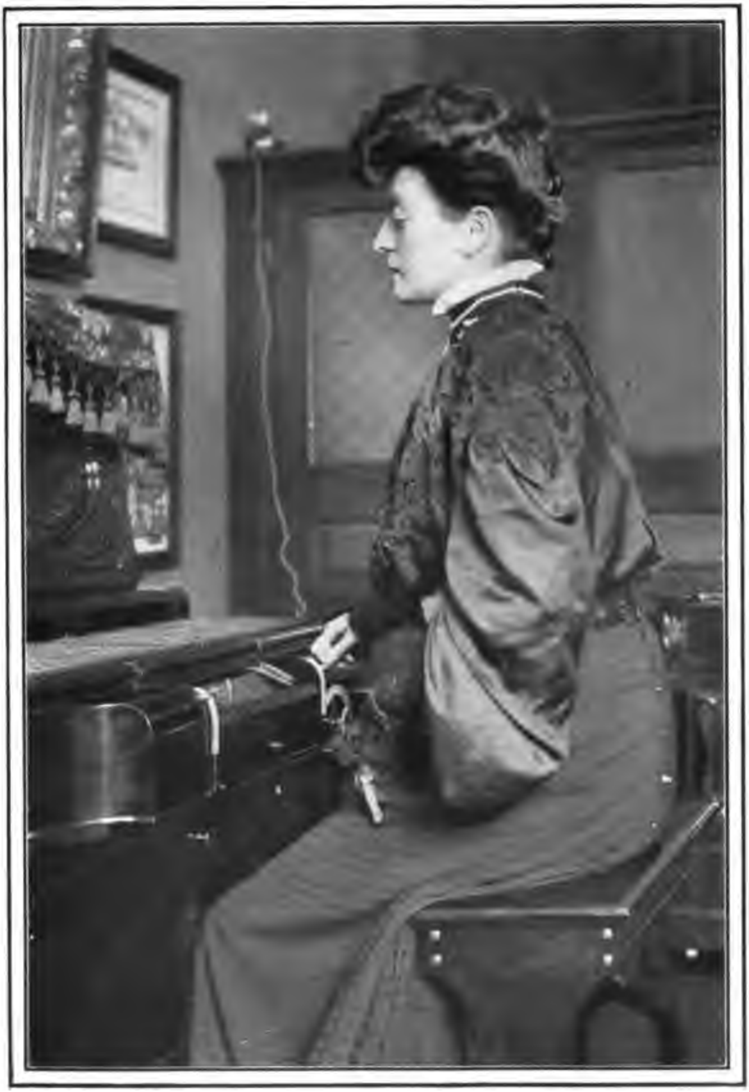


FIG. 90.—Series Connections of Two Lamps with Constant-potential Mains.

Necessity for resistance in lamps on constant-potential mains.



AN ELECTRIC PIANO PLAYER

A type of the "Harmonist" piano player, in which air pressure, produced by an electric motor, passes through a perforated sheet and so actuates automatic fingers which strike the keys

Enclosed arc lamps.

Carbon arcs are sometimes burned in the open air. Generally, however, they have a globe of glass, open either at the top or bottom, though generally at the top, placed around them. In order to increase the life of arc-light carbons, they are, under certain circumstances, enclosed in air-tight globes. In such cases, a small inner globe, formed of some refractory glass, is made to surround the arc, and is itself surrounded on the outside by a larger glass globe. Such lamps are called enclosed arc lamps. They are especially suitable for constant-potential circuits. The inner enclosing globe is egg-shaped.

Some characteristics of enclosed arc lamps.

After the arc has been established for six or ten minutes in an enclosed arc lamp, the inner globe becomes filled with carbon monoxide and carbon dioxide. This has the effect of shortening the length of the arc, and permits a pressure of eighty volts to be employed without increasing the length of the arc beyond about three-tenths of an inch. The consumption of the carbons is greatly decreased, since no burning can now take place, all the oxygen of the air having been combined with the carbon, either as carbon monoxide or carbon dioxide. The length of the life of the carbon is, therefore, increased to such an extent that ordinary carbons will last from 60 to 125 hours.

Carbons burning in enclosed arc lamps do not assume such a difference in shape as those burning in the open air. The positive carbon takes a shape very similar to that of the negative carbon, and is much flatter, as shown in Fig. 91, where the carbon on the left hand has the flattened shape characteristic of the enclosed globe, and that on the right hand a shape characteristic of a carbon exposed to oxidation by the surrounding air. While the enclosed

Current strength, pressure, and character of light of enclosed arc lamps.

lamp requires the same power as that for an open lamp, it requires nearly twice the pressure and but half the current strength. The light furnished by an inclosed lamp is steadier than that of the open light. Moreover, the distribution of the light renders it more suitable for out-of-door lighting than the open arc. The daylight value of the enclosed arc can be made to more closely resemble that of ordinary daylight by employing suitable colors on the enclosing globe to absorb the objectionable tints. As a rule, an opalescent globe is preferably employed for the inner globe, but, for photographic purposes, a clear globe is employed.

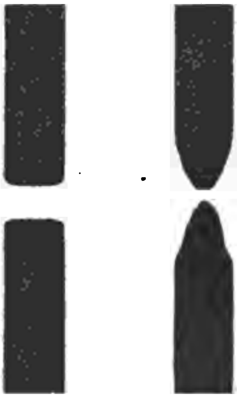


FIG. 91.—Appearance of Enclosed and Open Arc Carbons. The enclosed carbons are those on the left-hand side of the figure.

General Electric Company's enclosed arc lamp for multiple-connected circuits.

The General Electric Company's form of enclosed arc lamps for multiple-connected circuits, is shown in Fig. 92. This lamp is designed for circuits whose pressures vary from 100 to 120 volts. The arc voltage is arranged for a pressure of 80 volts when the line pressure is at 110 volts, and is arranged so that it may be adjusted for a somewhat higher voltage when the line pressure is from 115 to 120 volts. The resistance wire is wound on a spirally grooved porcelain drum. An adjusting clip is so arranged as to vary the value of the resistance coil. The magnet coils are provided with means whereby the length of the magnetizing circuit can be varied in order to suit different voltages.

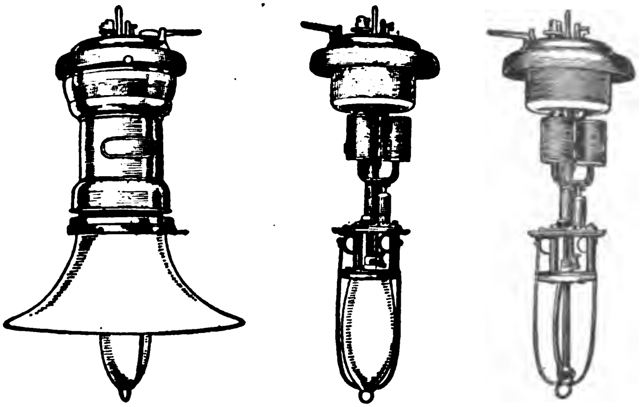


Fig. 92.—General Electric Company's Enclosed Arc Lamp for Constant-potential Circuits.

Some details of General Electric Company's arc lamp.

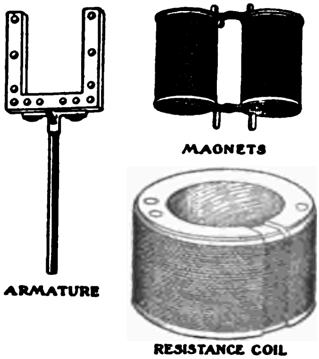


Fig. 93.—Some Details of General Electric Company's Enclosed Arc Lamp for Multiple-connected Circuits.

The inner or enclosing globe is shown in the central figure, but is removed in the figure on the right. In Fig. 93, is shown the resistance coil, adjusting clips, magnet coils, and armature employed in this form of lamp.

Another form of enclosed arc lamp, suitable for use on multiple-connections on constant-potential mains, is shown in Fig. 94, and is known as the Manhattan enclosed arc lamp. It operates with 5 ampères, at 85 volts, on 120 volt circuits, and at 80 volts on 110 volt circuits. The resistance is wound on a grooved porcelain cylinder, placed at the top of the lamp. As in the preceding type of lamp, the resistance coil is so arranged that it can

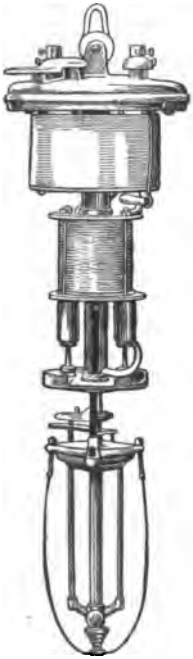


Fig. 94.—Manhattan Enclosed Arc Lamp.

Manhattan enclosed arc lamp.

be adjusted for circuits whose pressures vary. Both the inner globe and the enclosing outer globe are closed at the bottom, as shown in Fig. 95. The upper carbon employed is 12 inches in length and a half an inch in diameter. The lower carbon is five inches in length and a half an inch in diameter. With a 5 ampère current, these carbons will burn for about 150 hours.

A more satisfactory distribution of the light from arc lamps can be obtained by employing a greater number of lamps, each of which produces a smaller amount of light, but requires a smaller amount of energy to operate it. Such lamps are called low-energy or low-current lamps. Some of these low-current lamps are operated with a current as small as 2¾ ampères. Although satisfactory, generally, for street lighting, yet when a high voltage is employed the color of the light is objectionable. This difficulty has been remedied by a form of lamp, constructed by the General Electric Company, called the twin-carbon lamp. Here two pairs of series-connected carbons are simultaneously separated, so that the two arcs are burning at the same time within the lamp globe. By this arrangement, with a current of 2¾ ampères, a total pressure of 160 volts, or a pressure of 80 volts between the terminals of each pair of carbons, can be employed. The illumination produced by this lamp is very satisfactory,

Low-energy and low-current lamps.

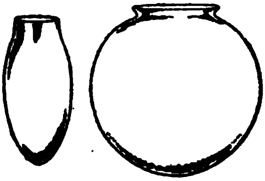


FIG. 95.—Inner and Outer Globes for Manhattan Enclosed Arc Lamp.

General Electric Company's twin-carbon arc lamp.

and the daylight color of its light approaches closely to that of sunlight. The General Electric Company's lamp of this type is shown in Fig. 96. As will be seen, only a single enclosing globe is employed, as shown in the lamp on the right-hand side of the figure. This globe, however, is furnished with a porcelain reflector, placed above it, as shown at the left-hand side of the figure. The twin-carbon lamp must not be confounded with the double-carbon lamp, which will be shortly described, where two pairs of carbons are employed in the lamp, but where the arc is only established between one pair at any one time.

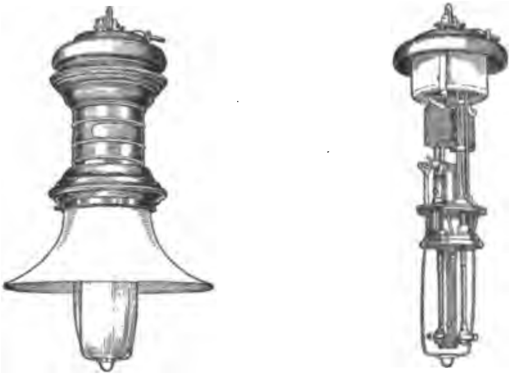


FIG. 96.—General Electric Company's Twin-carbon Enclosed Arc Lamp.

The advantages possessed by various forms of arc lamps for street lighting are thus discussed by Professor Ryan, in a paper entitled "The Relative Merits of Open and Enclosed Arc Lights for Street Illumination."

"Again returning to the question of low-energy lamps, one might well ask, why not carry the arguments for small units down to incandescent lamps and do away with arcs entirely? This might be

Professor Ryan on advantages of various forms of lamps employed for street lighting.

quite possible were it not that one of the essential requirements of good lighting is that the buildings and other objects on the street be illuminated to a considerable height above the ground. Arc lights fulfil this requirement by flooding the buildings with light, thus producing a general diffusion which gives the street an illuminated appearance which can not be obtained with incandescent lamps, unless they are placed very high and at such short intervals as to make their use prohibitive from a cost point of view; further than this, the light from incandescent lamps, in common with all other comparatively low temperature sources, lacks the luminosity or brilliancy obtainable from the electric arc.

"The incandescent lamp fills a very useful street lighting field of its own, and there is little fear of its encroaching upon the arc where light of considerable volume is required.

"In general, the foregoing can be briefly summed up in five conclusions.

"1st. Open Arcs give a higher maximum candle-power than enclosed arcs of corresponding wattage, but the maximum candle-power is in an undesirable direction, and the light fluctuates through very wide limits.

"Enclosed Arcs give a higher candle-power through the most useful angles from 3° to 10° below the horizontal. The light from the enclosed arc is more uniform and steadier, and generally superior from an illuminating point of view to the open arc.

"2d. DirectCurrent Enclosed Arcs produce slightly higher candle-power than alternating enclosed arcs of corresponding wattage, but so far as illuminating value is concerned, the two lamps are, generally speaking, on a fair basis of equality, both being superior to the direct current open arc.

"3d. Opal Enclosing and Clear Outer Globes will light relatively further than any other combination, and clear enclosing globes should never be used except for photographic purposes, where actinic rays are essential.

"4th. Small Unit Arcs will illuminate proportionately greater distances than large units for a given expenditure of energy.

"5th. Incandescent Lamps do not illuminate brilliantly to a sufficient height above the street surface to produce the effect of good lighting, and are therefore not comparable with arc lights."

Number of arc lamps per mile for street lighting.

The number of lamps required per mile for purposes of street lighting will naturally depend on a variety of circumstances, such, for example, as the distance between cross streets, length of the blocks, etc.; yet, generally, for such purposes, it may be said that a far better general illumination is obtained by means of a number of smaller units of light, and with, moreover, a higher economy.

CHAPTER XII

ARC-LIGHT CARBONS AND ALL-NIGHT ARC LAMPS

> "When night
> Darkens the streets."
> —*Paradise Lost,* Book I, Line 498

PIECES of charcoal or short rods of gas-retort carbons, although answering very well for the production of electric light for lectures, or for use for a few hours only, are unsuited for use during an entire night. They are still more unsuited for such cases as lighting the inside of rooms which are dark even during times of bright sunlight, and where, as a consequence, even more prolonged running is necessary. Even if it had been possible to obtain such carbons in sufficiently great lengths, it would have been difficult to supply the great demand that soon arose from the wonderful increase in the number of arc lamps employed in different parts of the world. Fortunately for the art, artificial carbons can be made of far better quality and greater length than is possible from either of the before-mentioned sources.

Necessity for artificial carbons for arc lighting.

Some idea of the enormous use of arc-light carbons may be gained from the fact that in the United States census returns a production is recorded of nearly 173,000,000 carbons for arc lamps during the year 1900. Taking the length of the average carbon at twelve inches, this would be equivalent, in round numbers, to 32,750 miles of carbon rods

Enormous annual use of arc-light carbons.

placed end to end, an amount sufficient to reach about one and one-third times around the earth at the equator. The above would certainly have been much larger were it not for the fact that, by the use of enclosed carbon-arc lamps, renewals are required but once in every hundred hours, whereas, with the open-arc type, such renewals would have been required each twenty-four hours.

How the density and conducting power of artificial carbons may be increased.

As we have already seen, Bunsen was the first to manufacture artificial carbons for the carbon plates of his voltaic cell. In order to improve the conducting power of such carbons by increasing their density, Bunsen, after baking his carbons, dipped them in a strong solution of sugar and water, and then again baked them. In this way, the carbon deposited in the porous mass increased its density, and, consequently, increased its conducting power. At the same time, the exposure of the carbon to a high temperature for a prolonged period also increased its density and consequently its conducting power.

Staite and Edwards's artificial carbons.

In 1846, Staite and Edwards, who had made numerous improvements in arc lamps, invented a variety of artificial carbons somewhat similar to those of Bunsen, which, however, were intended directly for the purposes of artificial carbons employed in their arc lamps.

Jacquelain's artificial carbons.

Many inventions were made in the direction of artificial carbons for arc lights between the years 1846 and 1852. These different inventions were directed mainly to increasing the purity of the carbon and thus improving its conducting power, and to increasing the length of time that the carbon could be employed for the production of the arc light. Jacquelain, a Frenchman, especially improved the quality of the artificial arc-light carbons. But the improvement in these various directions that was of the greatest value to the art of arc lighting was that of Archereau, another Frenchman, who made a better variety of carbon rods and plates by forming the material into a pasty mass, consisting of various pulverized carbons mixed with carbonizable liquids. It was Archereau who first formed such pasty masses into the desired shapes by forcing them through a suitably shaped aperture by pressure obtained from a hydraulic press. Carrè, another Frenchman, still further improved this process. He employed the following mixtures for his carbons; viz., 15 parts of pure coke, 5 parts of calcined lampblack, both reduced to the shape of very fine powder and mixed with a syrup containing from 7 to 8 parts of sugar, to which a little gum was added. This mixture was made into the required consistency with water, after which it was forced through suitable draw-plates by hydraulic pressure. In order to permit the employment of a stiffer paste with a smaller quantity of water, the substance was heated prior to being placed in the press. As the rods of the artificial carbons came out of the press they were received on grooved tables covered with charcoal dust, and were then placed in a furnace, where they were heated to a full red heat for a period of about five hours. On their withdrawal from the furnace they were again dipped into a syrup of boiling sugar and reheated, for the purpose of increasing their density and length of life.

Archereau's artificial carbons.

Carrè's artificial carbons.

Carbonizing process.

In order to still further increase the density of artificial carbons and so prolong their life, Napoli, another Frenchman, conceived the idea of placing

Napoli's process of increasing density of artificial carbons.

the artificial carbons in a vacuous chamber after they had been fully carbonized. When the carbons were placed in this vessel, before the vacuum was applied, the carbons were heated for the purpose of expelling all their absorbed gases. They were then surrounded by a solution of boiling syrup, and subjected to a strong steam pressure, for the purpose of driving the sugar solution throughout all parts of their mass. On removal from this vessel, the carbons were again exposed to a prolonged high temperature while out of contact with the air. In this way, the quality of the carbons was greatly improved, and their length of life increased.

Process employed to-day for manufacturing artificial carbons.

The method employed in this country for the manufacture of arc-light carbons differs somewhat from any of the before-described methods, although, in general, the processes are somewhat similar. Various carbonaceous materials, such as coke, especially petroleum coke, lampblack, etc., are crushed and placed in retorts, where they are exposed to a high temperature for periods varying from 10 to 50 hours, according to the character of the carbons required. This prolonged heating improves the purity of the carbons, and increases their conductivity. The carbon is next ground into a fine powder and bolted, this process producing a fine carbon flour. The flour is then placed in mixing kettles, where it is mixed with a binding material consisting of crushed pitch. These kettles are kept hot so as to facilitate the mixing. After this mixture has been thoroughly effected, the material is cooled, crushed, ground and bolted, so that a carbonizable flour is obtained.

Carbonizable flour.

From this point on, the character of the process depends on the kind of carbon that is to be obtained. As manufactured to-day, artificial carbons belong to two classes; viz., they are molded or they are squirted. In molded carbons the carbonizable flour is placed in a steel mold and the cover then placed over it. The mold is then slowly heated in an oven until the mixture becomes pasty, when the mold is taken from the oven and placed under a powerful hydraulic press, where it is subjected to a pressure of from 100 to 400 tons. When forced or squirted carbons are manufactured the process is as follows: The carbonizable paste, made from the carbonizable flour by heating, is forced through a draw-plate of the proper proportions by the action of a hydraulic press. As the carbons issue from the press they are received on a table and cut into the proper lengths. Cored carbons are formed by forcing the mass through an aperture shaped so as to leave a cylindrical opening one-eighth of an inch in diameter throughout the entire carbon. This hole is then filled with softer carbon.

Molded and forced carbons.

Cored carbons.

Both in the case of molded and squirted carbons, after the former have been removed from the mold, and after the latter have been received from the hydraulic press, they are subjected to the action of prolonged heat, by means of which the volatile matter they contain is driven off, and the carbonizable matter decomposed, and its carbon deposited within the pores of the mass. This heating requires to be carried on slowly, to prevent the warping of the carbons. The carbons are placed in a furnace, where they are covered with several layers of sand, so as to prevent access of air. They are then exposed to the action of a high heat for a period that, in some cases, extends to several weeks. In this way, carbons of remarkable purity, uniformity, conducting power, and long life are obtained.

Exposureof carbons to prolonged action of heat.

Copper-coated carbons.

In order to still further improve the conductivity of carbons, they are sometimes covered on the outside with a coating of copper, deposited on the surface by electro-plating. This copper coating has the effect of preventing the carbons from burning too rapidly during their exposure to the air. The value of the coating in this respect may be judged from the fact that, while 12 inches of ordinary ⅝ carbon will last 10 hours in the ordinary 10 ampère, 45 volt lamp, when no electro-plating is on it, it will last for 14 hours, under the same conditions, when electro-plated. As a rule, only the carbons that are employed in open globes are electro-plated. Cored carbons are seldom, if ever, so protected.

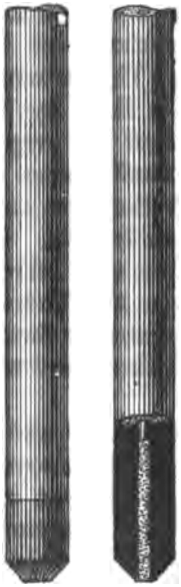


Fig. 97.—Solid and Cored Carbons for Arc Lights. Note that nearly all the surface of the solid carbon is electro-plated with copper.

Solid and cored carbons.

The general appearance of a solid carbon protected by a copper plating, and a cored carbon not so protected, is seen in Fig. 97, the solid copper-coated carbon being shown at the left-hand side and the cored carbon at the right-hand side of the figure.

Longer burning carbons required for long-burning lamps.

But no matter how great the care that had been taken in order to increase the life of the carbons, they were not found, when burned in the open air, to last for the nine hours or longer during which they must continue to burn through the long winter nights in high latitudes. It is true that an increase in the lifetime of a carbon can be obtained by increasing the length of the carbon rod, and, where arc lamps are employed for outside illumination, such an increase in the length of the carbon rod is possible, yet, if this increase were carried too far, the length of the lamp would become unwieldy, where the lamp rod was employed, since the length of such lamp rod would necessarily be as long as that of the carbon itself, as will be seen in an old form of lamp shown in Fig. 98, where the tall tube C, attached to the top of the lamp, receives the carbon rod. This type of lamp, however, is now generally replaced by lamps in which the feeding is effected by means of a clamp that surrounds the carbon rod directly, thus doing away with the lamp rod, and materially shortening the length of the lamp. This last feature is especially desirable for inside illumination of rooms, where the ceilings are comparatively low.

Means were required, therefore, in these early days in the art, for devising some form of arc lamp whose carbons would last for a period of nine hours and over, or, as they were generally called, some form of all-night arc lamp.

Wright's all-night disk lamp.

One of the earliest forms of all-night lamps was that devised by an Englishman, named Wright,

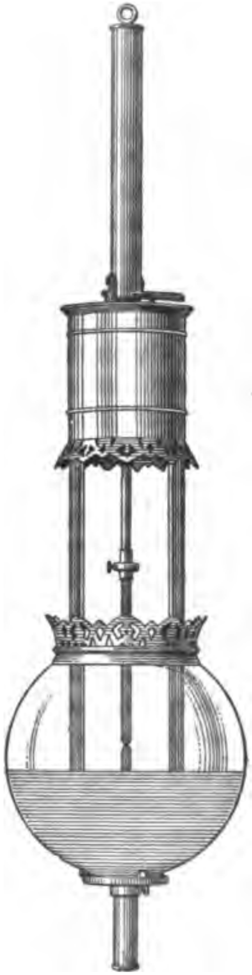


Fig. 98.—Old Form of Arc Lamp with Lamp rod, showing inconvenient length of lamp.

who took out a patent in England for "A method of producing a permanent light by continually presenting one or more fresh points or surfaces of carbon or other suitable material to the path of the electric current." For this purpose, Wright employed two separate rotating carbon disks, placed at right angles to each other. The rotation of the disks was obtained by means of wheelwork, driven by a spring or other prime mover. Matters were so arranged that the disks were first brought into contact, and afterward slowly separated, thus striking the arc between them.

Wright's use of two separate rotating carbon disks.

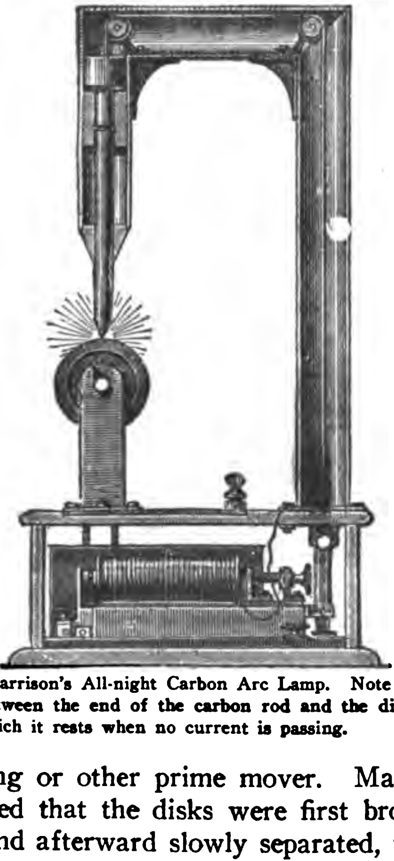


Fig. 99.—Harrison's All-night Carbon Arc Lamp. Note the formation of the arc between the end of the carbon rod and the disk against the surface of which it rests when no current is passing.

Wright's all-night lamp was modified by another Englishman named Harrison, who took out a patent for it in England, in 1857. The general details of Harrison's all-night lamp will be understood from an examination of Fig. 99. Here only a single disk is employed, the upper carbon consisting of a heavy cylindrical carbon rod. The arc is struck by means of an electro-magnet, shown in the lower part of the figure, the attraction of whose armature raises the upper carbon by means of a cord passing over pulleys, as shown.

Harrison's all-night disk lamp.

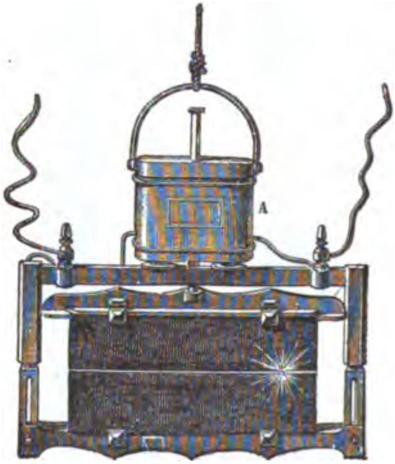


Fig. 100.—Wallace's All-night Rectangular Carbon Plate Arc Lamp. Note the fact that the arc is established at the point between the two plates, where the carbons are nearest together.

Wallace's rectangular plate all-night lamp.

Another form of all-night carbon arc lamp devised by an American named Wallace, is shown in Fig. 100. Here two rectangular plates of carbon are placed parallel, one vertically over the other. The lower plate is fixed, and the upper plate movable, being supported by the armature of an electro-magnet inclosed in the box A, at the top of the lamp. As in the ordinary arc lamp, when the current is not passing the two carbons touch. As soon as the current passes, the movement of the armature of the electro-magnet raises the upper carbon and establishes the arc between the two plates. Since such plates are never exactly parallel, the arc is started between them through the path of least electric resistance. As soon as the carbon at this part is consumed, the arc moves to another place, in this way travelling along between the two plates. Should the distance between the carbons become too great, the upper carbon is fed toward the lower carbon, as in the case of the ordinary lamp. The carbons of this lamp would last for about one hundred hours. Although this regulator is extremely simple, yet the light it produces is unsatisfactory, on account of the constant travelling of the arc.

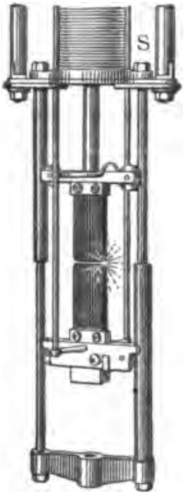


Fig. 101.—Pilsen's All-night Carbon Plate Arc Lamp. Note the practical identity of this lamp and that represented in Fig. 100.

Pilsen's plate all-night lamp.

A form of lamp similar to the preceding is shown in Fig. 101, and is called the Pilsen lamp, after the name of its inventor. As in the Wallace lamp, two carbon plates are employed, though of smaller width. The upper carbon is movable, being attached to the core of the solenoidal coil S. Like the Wallace lamp, the light produced is irregular, due to the travelling of the arc.

Double-carbon arc lamp.

The problem of producing a satisfactory all-night carbon arc lamp was finally solved by the employment of the double-carbon lamp. Here there are two separate pairs of carbons. The series and shunt magnets, that control the carbons, are so arranged that, on the passage of the current, only one pair is separated. In other words, the arc is only formed between one pair, the other pair remaining at too great a distance apart to have the arc established between them. As soon as the pair of carbons that are maintaining the arc are consumed, the current is automatically switched over to the other pair. A double-carbon lamp of the Brush type is shown in Fig. 102, at the lower part of the figure. In order that only

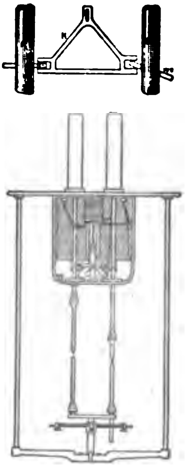


Fig. 102.—Brush's Double Carbon All-night Lamp.

a single pair of the carbons shall be able to maintain the arc between them at any one time, the double ring clamp or clutch K, shown at the top of the figure, has one pair of jaws, that is, those connected with the clamp W^2, wider than the other at W^1. Consequently, on the attraction of the lifting magnet, the clutch W^2, connected with the wider jaws, is first lifted, and thus separates its carbons higher than the other, so that the arc is first established between the carbons connected with W^1; for, although both rods are lifted at each movement of the armature, yet the distance between the carbons connected with W^2 is too great to permit the arc to form between them. When, however, the carbons connected with W^1 are consumed, so that the distance between them becomes too great for the arc to be continued, then the other pair is brought into action, and so remain until consumed.

Brush double-carbon arc lamp.

The double-carbon arc lamp is generally employed on series-connected open-globe lamps. Its mechanism is simple, and its operation satisfactory. For indoor lighting, where multiple-connected enclosed arc lamps are now generally employed, the great increase in the length of life of the carbons has practically solved the problem of the all-night arc lamp, since, in this way, lamps can be readily obtained which will not need recarboning for periods as great as say 150 hours.

Enclosed arc lamp best form of all-night lamp.

CHAPTER XIII

ALTERNATING-CURRENT LAMPS

> "It is clearly shown that the alternating-current arc is a sequence of direct-current arcs, alternating in polarity, and that each wave of current produces very clearly and distinctly all the attributes of the direct-current arc. The hot positive carbon with its white hot crater, from which extends the fan-shaped blue light of the arc to the small white tip of the colder negative carbon, will be seen to die away, and all light goes out except the glow of the red-hot carbons, and then light appears again with the current reversed."—*Alternating Arc Lamps:* PUFFER

Advantages of alternating electric currents for artificial illumination.

THE advantages possessed by alternating electric currents for high-tension transmission render arc lamps by means of alternating-electric currents very advantageous in many respects. Where the lamps are scattered, and are situated at comparatively great distances from the centre of distribution, alternating currents can be transmitted over the conducting lines at high pressures, and transformed to lower pressures by means of step-down transformers inserted between the line circuits and the lamps.

Alternating electric lamps for constant-current and constant-potential circuits.

Alternating-current arc lamps are employed both on constant-current and on constant-potential circuits. Since, in such lamps, the lower carbon is consumed nearly as rapidly as the upper carbon, when such lamps are furnished with enclosed globes the globes are required to be of comparatively great length, so as to permit the use of a long negative carbon. This is necessary, since the time during which the lamp can be maintained without recarboning will depend on the length of the negative carbon. With six inches in length of negative carbon on an alternating-current enclosed arc lamp, this carbon will last, with the pressures ordinarily employed, for a period of from eighty to one hundred hours.

Constant current transformer.

For enclosed arc lamps, operated in series on alternating-current circuits, a constant-current transformer is necessary, so that the current strength of the circuit shall be maintained constant, no matter how many lamps may be cut out or cut into the circuit, up to the full load. This transformer is situated in the central station and is so arranged that it automatically adjusts the distance between its primary and secondary coils, so as to maintain a constant current, notwithstanding variation in the number of lamps in operation.

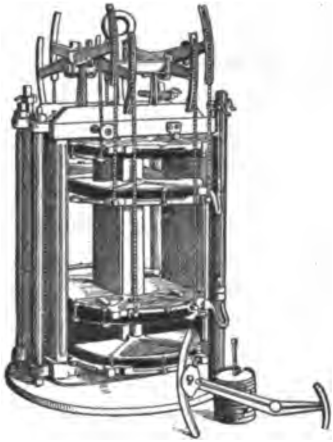


FIG. 103.—General Electric Company's Constant-current Transformer for Series-connected Arc Lamps.

A constant-current transformer, of the General Electric Company's type, is shown in Fig. 103. Here

General Electric Company's constant-current transformer.

the primary and secondary coils consist of flat coils placed around a laminated core, of the double magnetic circuit type. This circuit is provided, as shown, with three vertical limbs. Where the transformer is intended to supply current for from twenty-five to thirty-five lamps, the primary and secondary coils are placed, respectively, at the bottom and top of the transformer. One of these coils, generally the lower or the primary, is fixed, while the other is balanced so as to be capable of readily moving toward or from the lower coil. This is accomplished by the employment of a counter-weight, so adjusted that it will exactly balance the movable coil when the repulsion, which will take place between the coils as soon as currents are passing through the primary and secondary, is taken into account. Any increase in the strength of such current, caused by cutting out the lights on the circuit, is prevented from taking place by the movable coil being repelled from the stationary coil, on account of the mutual repulsion existing between them. This moves the secondary over the primary, and so decreases the amount of flux passing through it, and, hence, the amount of voltage it produces. On the contrary, any decrease in the current strength, which would tend to be caused by an increase in the number of lamps in the circuit, will be prevented by the counter-weight moving the secondary coil nearer to the primary, and so permitting the secondary to produce a greater voltage by reason of the greater amount of flux passing through it. In constant-current transformers, intended to supply a great number of lamps, two primary and two secondary coils are employed. In such cases the primary coils are placed at the top and bottom of the transformer, and the two movable secondaries are so balanced as to be able to move readily toward or from the primaries. Another view of a General

Automatic regulation of constant current.

THE BROOMSTICK TRAIN

"Since then on many a car you'll see
A broomstick as plain as plain can be.
On every stick there's a witch astride;
The string you see to her leg is tied."—*O. W. Holmes*

Electric Company's constant-current transformer, with the counter-weight in position, is shown in Fig. 104.

Alternating current electro-magnets.

It might be supposed that alternating-current electro-magnets would be impracticable, since the polarity is changed with every change in the direction of the current. In point of fact, however, when an alternating electric current is sent through a magnetizing coil, there will be produced a continuous attraction of the armature. It is for this reason that alternating-current magnets can be employed for the regulation of arc lamps. When such magnets are provided with cores, it is, of course, necessary that these be thoroughly laminated, in order to prevent the setting up of eddy currents. When a solenoidal coil is employed with a thoroughly laminated core, it is found that such a core possesses the valuable property of being attracted with greater force when the core is projecting outside the solenoidal coil.

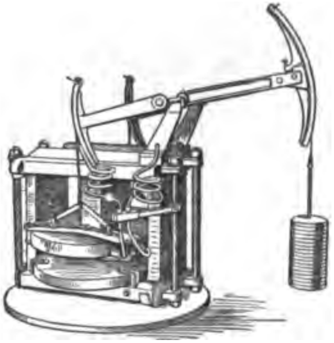


Fig. 104.—Another View of General Electric Company's Constant-current Transformer for Series-connected Lamps.

A General Electric Company's series alternating-current arc lamp is shown in Fig. 105. Since this lamp is intended for use on a series circuit, it must contain both a series and a shunt magnet. It operates on the differential principle, already explained in connection with direct-current series-connected lamps. In this lamp the cores of the magnets are laminated, in order to avoid loss by eddy currents. A starting resistance is provided as in all alternating series lamps. A mechanical cut-out is provided in case of accidents to the carbons or on opening the circuit of any lamp. This cut-out, as seen in the figure, is attached to a hanger bar, which is insulated, so as to stand the test of a constant pressure of 40,000 volts. The hanger bar is capable of holding a weight of 700 lb., a wide margin of safety, since the weight of the lamp itself is only 30 lb. A series alternating-current lamp, provided with its outer globe and a reflecting shade, and suspended to the line circuit, is shown in Fig. 106. The box at

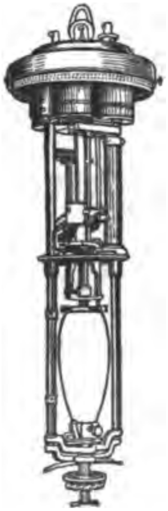


Fig. 105.—General Electric Company's Alternating-current Lamp for Series Circuits.

General Electric Company's alternating-current series-connected arc lamp.

the top of the figure is provided with a mechanical switch for placing the lamp in or removing it from the circuit.

Advantages of series alternating arc lamps.

Series-connected alternating-current arc lamps have proved to be well adapted for the general purposes of street illumination, but are unsuited for inside illumination, such as department stores, mills, and factories, by reason of their dangerous pressure. The use of series-connected alternating-current enclosed arc lamps offers considerable advantages over ordinary open arc lamps. The light, as a general thing, is steadier, its daylight value can be made to approach more nearly that of sunlight; moreover, the cost of the lamp maintenance is considerably reduced, since the lamps require to be trimmed or recarboned only once in from eight to twelve days, according to the time of the year.

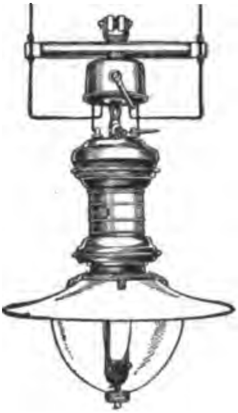


FIG. 106.—General Electric Company's Alternating-current Lamp. Complete with case, outer globe, and reflecting shade.

The enclosed alternating-current arc lamp, when employed for out-door illumination, may be sus-

Advantages of enclosed alternating-current arc lamps.

pended from a mast-arm. When reflectors are employed, which are generally formed of porcelain, the lamps can be placed nearer to the ground than in the case of open arcs. This is a marked advantage, since, with the open arc lamps, which are placed on the top of high poles, the wide distribution of the light is obtained at the loss of considerable intensity of its illuminating power. The distribution of the light of the enclosed arc lamp is such that these lamps can be placed near to the object to be illumined. These lamps, when employed for street lighting with reflectors, are generally placed at a distance of from eighteen to twenty feet from the ground.

Phenomenal increase in use of alternating-current enclosed arc lamps.

Perhaps the best proof of the general belief in the advantages of enclosed alternating-current arc lamps is found in the wonderful increase in the use of such lamps. Between the years 1895 and 1896, there were comparatively few alternating open arc lamps in use. During 1896, from 1,000 to 1,500 alternating lamps were introduced by the central stations. In 1897, the first satisfactory enclosed alternating lamp was made commercially successful, and from this time on, the growth has been rapid and constant. In the years 1897 and 1898, nearly 30,000 lamps were installed; during 1899, 30,000 additional lamps were required; during 1900, between 50,000 and 60,000 lamps were installed; and an increase is still going on.

The following conclusions, reached by a committee on light, appointed by the Board of Legislation, of Cincinnati, in 1901, after a careful study of the different systems employed for street lighting in St. Louis, Chicago, Milwaukee, Pittsburg, Allegheny, Edgewood Borough, Baltimore, Washington

City, Philadelphia, New York, Hartford, Boston, appear to be fully sustained by the actual facts:

Conclusions reached by committee on light appointed by Cincinnati Board of Legislation in 1901, concerning different methods of street lighting.

"The experience of your committee, therefore, in all these cities visited would tend to show that electric lighting of the open type or enclosed lamps gives a better illumination than either gas or gasoline lamps, either of the open flame type or equipped with incandescent gas burners. The consensus of opinion seems to be that the enclosed arc lamp is superior to, and an improvement on, the open type of arc lamp, and that of the two kinds of inclosed arc lamps the alternating is better than the direct-current type, because a greater portion of the light is thrown in a horizontal direction, and because, therefore, the general illumination of the street is more uniform. Another advantage of the alternating-current type of lamp is that lamps of 1,200 candle-power can be used, if desired, from the same dynamo that furnishes the 2,000 candle-power lamps, and, therefore, by the use of the smaller candle-power a greater number of them can be used at the same cost per year for lighting, enabling the lamps to be placed much closer together. The use of an increased number of lamps, giving the same amount of light more evenly distributed, and at no greater cost, would be an object well worth striving for."

United States Census Bureau Report for 1900 on increase of enclosed alternating-current arc lamps for street lighting.

The United States Census Bureau, for October, 1900, in giving results of the 12th Census of the United States, states that above 150 cities, having populations of 25,000 and upward, have replaced open arcs and installed enclosed arcs in their stead. The installation of enclosed arcs for street lighting has been so rapid that fifty-one of these cities, or thirty-three per cent of all, have permanently adopted arc lights of the enclosed type. It is interesting to note that, out of the fifty-one cities thus referred to which have adopted enclosed arcs and abandoned open arcs, twenty-six have a population of 50,000, while ten of them have a population of 100,000 or more, according to the Census of 1900.

Use of step-down transformer.

Where a single arc lamp is to be taken from a high-pressure circuit, the high-pressure wires are connected to the primary of a step-down transformer, the secondary terminals of which are connected with the terminals of the arc lamp, as shown in Fig. 107. In this circuit a meter has been placed in the secondary circuit, so as to determine the time during which the current has been supplied to the lamp, thus fixing the proper charge for service.

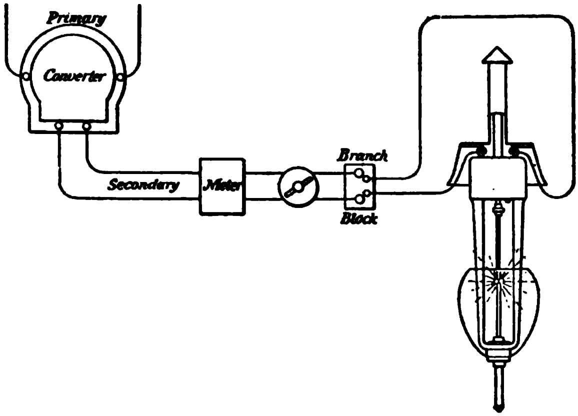


Fig. 107.—Circuit Connections of Alternating-current Lamp. Note the connections of the secondary mains with the electric meter, switch, and arc lamp.

Where constant-potential mains are already installed for the supply of incandescent lamps, alternating-current lamps may be employed, connected with such mains in parallel. Suppose, for example, that three lamps are to be connected in parallel to such constant-potential mains, and that the mains are supplied with a constant electric pressure of say from 50 to 300 volts. Suppose, moreover, that the lamps employed operate best with a pressure of 33 volts. Now there are three ways in which the pressure of 50 to 100 volts on the constant-potential main can be reduced to the 33 volts required for the proper operation of the lamp. These three methods are shown in connection with Fig. 108, where *s s* represents the constant-potential mains, carrying say

Alternating-current lamps on constant-potential mains.

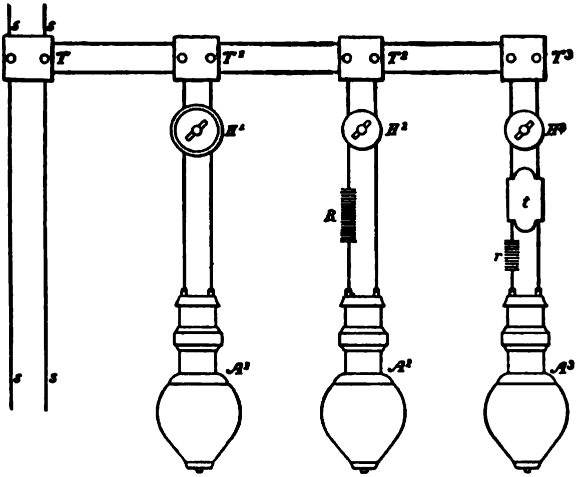


Fig. 108.—Three Methods of Reducing Pressure of Alternating-current Lamp to Constant-potential Mains.

either 50 or 100 volts alternating pressure; T, T^1, T^2, T^3, represents safety-fuse cut-outs; H^1, H^2, H^3, are switches for controlling the arc lamps A^1, A^2, A^3.

Choking or economy coil.

At A^1, in addition to the switch H^1, there is provided a choking coil or, as it is generally called for such purposes, an economy coil. This coil is so proportioned as to cut down the pressure to say the thirty-three volts necessary for the proper operation of the lamp A^1. At A^2, in addition to the switch

Use of resistance with step-down transformer.

H^2, there is provided a resistance, R, which is proportioned to cut down the pressure to thirty-three volts. At A^3, in addition to the switch H^3, there is provided a step-down transformer, *t*, which supplies a pressure of about thirty-five volts. A small resistance, *r*, inserted in the circuit of the secondary, is provided to maintain the pressure of the lamp terminals at about the thirty-five volts required for its proper operation. Of the three methods described above, that of the economy coil is the simplest and the most economical, since it requires a smaller expenditure of energy than either the resistance or the step-down transformer.

CHAPTER XIV

ARC-LAMP FIXTURES AND APPURTENANCES

"The sun's rim dips; the stars rush out;
At one stride comes the dark."
—*The Ancient Mariner:* COLERIDGE

IN any system of arc lighting the lamps are hung or suspended where they will best illumine the spaces to be lighted. Various methods for suspending such lights are employed, but whatever be the method, means must be provided so that the attendant or lamp trimmer can readily reach the lamp for properly cleaning the lamp and its globes, and for replacing the carbons that have been consumed during the maintenance of the arc. This replacing of the carbons is generally called recarboning.

Arc lamps must be readily accessible.

For out-door lighting a number of high candle-power arc lamps are sometimes placed at the top of a tall pole, as shown in Fig. 109. Where the spaces to be lighted are sufficiently open this method of illumination produces an effect not unlike that of full moonlight. The improvements, however, that have recently been made in enclosed arc lamps, which, as we have seen, produce a much more uniform distribution of light, and which, when of the low-economy or low-current type, can be employed in greater numbers, render it possible to obtain a more uniform and better distribution of the light by placing the lamps near the surface to be illumined.

Tower lighting.

Wasteful illumination when lamps are placed at top of high pole or tower.

Such a method is less wasteful than when the lamps are placed at the top of a high pole or tower. Where, however, the tower system of electric lighting, as this method is called, is employed, means must be provided for the lamp trimmer to reach the lamps. This is afforded either by means of steps or ladders.

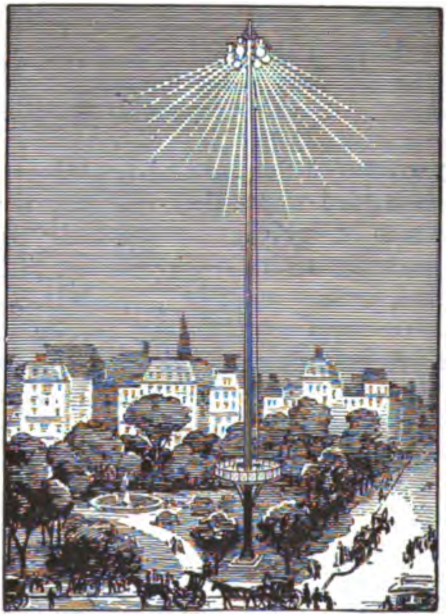


FIG. 109.—System of Tower Arc Lighting. Although a pleasant and well diffused lighting is ensured, yet the amount of light received by objects near the ground is comparatively small.

Means adopted for readily lowering the arc lamp.

Sometimes, however, means are adopted for readily lowering the arc lamp. This can be done as represented in Fig. 110, where an iron frame supporting the lamp can be lowered by means of a rope, so as to permit it to be readily reached by the lamp trimmer. A conical hood placed above the lamp serves to protect it from the weather. Since the inside of this hood is smooth and whitened, it also acts as a reflector.

Another method of suspension is that shown in Fig. 111. This is called a cross-wire suspension, and is sometimes employed for hanging a lamp directly over the middle of a street. Here the lamp can be lowered by means of a pulley and cord, C C C C. In many forms of supports, such, for example, as pole supports, shadows are cast by the pole. In order to avoid this, various methods are adopted for supporting the lamp outside of the direct line of the pole. To avoid this the lamp is attached to arms that project beyond the pole. In

Cross-wire suspension.

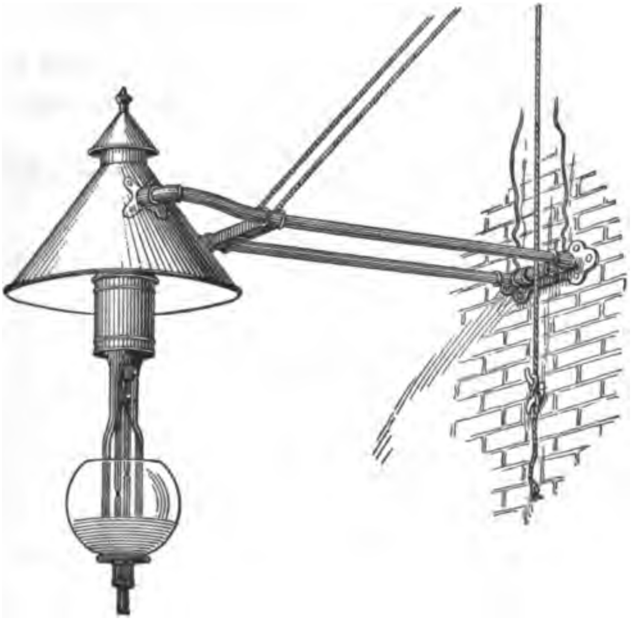


Fig. 110.—Cross-wire Suspension for Arc Lamp. Note that the lamp employed here is of the all-night type.

Mast-arm support.

such cases a very convenient method for readily raising or lowering the lamp is by what is called the mast-arm support, as in Fig. 112, where the mast-arm consists of a main rod formed of iron tubing with guy rods and cross rods for stiffening and supporting it on a frame or bracket directly mounted on the pole. This arrangement permits the lamp to be lowered to the side of the pole where it can readily be reached by the lamp trimmer.

Various forms of switches operated by hand are employed for the purpose of placing the arc lamp in

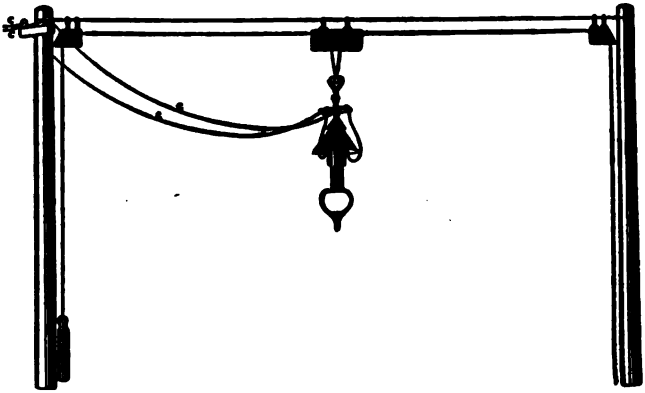


FIG. 111.—Cross-wire Suspension for Arc Lamp. Note the means employed for lowering the lamp.

a circuit or removing it from the same. Such switches were formerly placed on a board, called a hanger board, to which the lamp was suspended. Hanger boards are now generally displaced by insulated hangers, of the form shown in Fig. 106, the switch being placed directly below such hanger. The switch shown in Fig. 113, instead of being placed either on the lamp or on the hanger, is supported on a wall or post, in such a position as to be readily reached by the lamp trimmer. Such switches, how-

Hanger boards.

ever, should never be placed where they can be readily reached by the general public. This is especially true in the case of series arcs, where the pressure employed on the entire line is high, and, consequently, dangerous, should contacts occur so as to permit a person incautiously handling the lamp

Isolated arc-lamp switch.

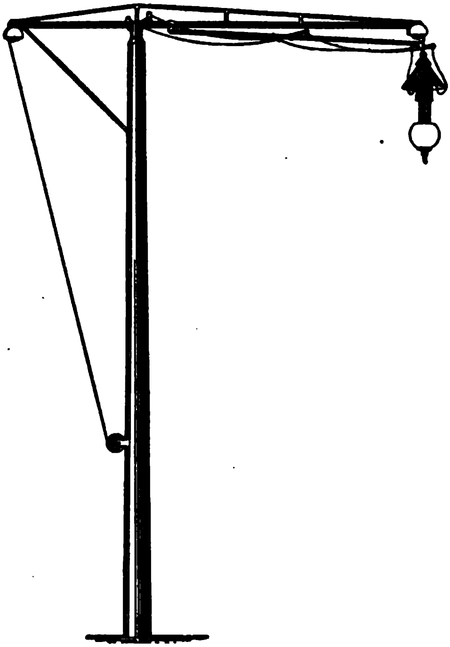


FIG. 112.—Mast-arm Support for Arc Lamp. Note the fact that there is nothing here to cast shadows in the space directly below the lamp.

to be exposed to the entire pressure. The hand switch represented in the above figure, is so arranged that the mains of the switch-handle automatically display the words "on" or "off," thus indicating the position occupied by the switch.

For the ready control of lamps employed for indoor illumination, such, for example, as in department stores, where the lamps are connected to constant-potential mains, a variety of suspension, called the "ceiling board," is employed. Here, as is shown in Fig. 114, the insulated suspension hanger is attached to a porcelain block, through which the conductors connected with the mains pass, ready for connection with the lamp terminals.

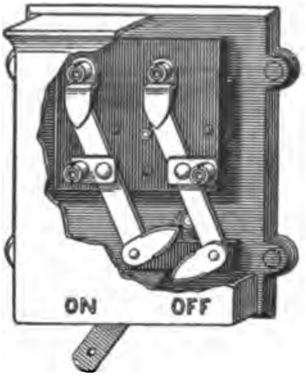


Fig. 113.—Mechanical Cut-out Switch for Arc Lamp.

For in-door lighting, considerable difficulty is sometimes experienced where heavy machinery is employed, as in weaving mills, where high-backed looms are installed, or in machine-shops, where either stationary or travelling cranes are used, in insuring that uniform distribution of light which is

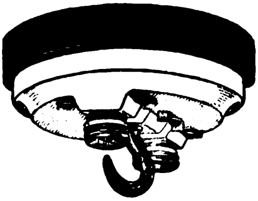


Fig. 114.—Porcelain Ceiling Board for Multiple-connected Arc Lamps.

Ceiling board

required for the examination, say at a distance of seventy-five feet from the lamps, of the fine threads employed in weaving, or the high-grade machine tool-work employed in machine-shops. For such purposes, the use of a shade is necessary. Here care must be taken not to employ shades that cut off too much light. The shape of the shade will depend on the proportion of light which it is desired to throw directly on the object to be illumined, as compared with the amount of light which is reflected from the walls and ceiling of the room. Where these are whitened, as should generally be done for in-door illumination, where a considerable portion of the light is required to be thrown on the object by reflection from the walls and ceiling, the full porcelain shade, shown at No. 3, of Fig. 115, throws too much of its light directly downward, and permits too little to reach the walls and ceiling, so that the porcelain shade, seen at No. 4, is preferable. For factories, where porcelain shades are liable to breakage, metallic shades, such as represented in Nos. 1 and 2, are preferable.

Care necessary in use of shade on lamp to obtain character of illumination required.

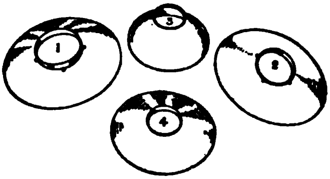


FIG. 115.—Shades and Reflectors for Enclosed Arc Lamps.

In some cases, where it is desired to throw the light upward, a form of inverted arc lamp is employed, such as seen in Fig. 116. Here the positive carbon is placed below the negative. In such cases, it is generally better to arrange the lamp mechanism so as to feed the negative carbon. In inverted arc

Inverted arc lamp.

lamps the negative carbons may be made somewhat thicker than the positive, owing to the somewhat more rapid consumption, due to the heated gases rising from the arc. For arc lamps globes of various shapes are employed, such, for example, as those represented in Fig. 117. Considerable care is necessary as regards the character of the globe employed, since, no matter how it may be made, an appreciable loss occurs during the transmission of light through it. Globes are formed either of clear transparent glass, or opal glass, or of translucent glass and opal glass, called alabaster. Arc-light globes are either blown or molded. In either case care should be taken to avoid irregularities in the thickness of the glass, since such irregularities in the globes will produce marked unevenness in the illumination. As a rule, molded globes are preferable to

Clear, opal, and alabaster globes for arc lamps.

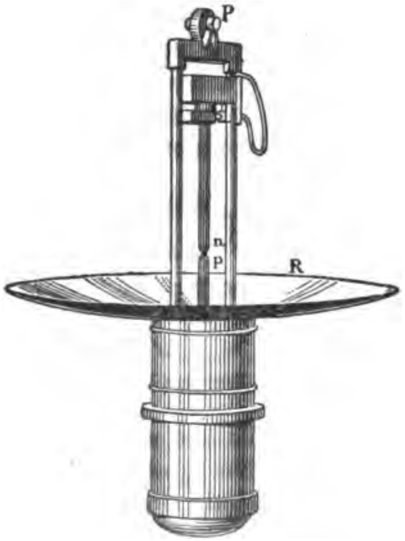


FIG. 116.—Inverted Arc Lamp. Note here that the negative carbon is somewhat thicker than the positive carbon.

blown globes, but, even here, care must be taken to avoid the irregularities in the light produced by variations in the thickness of the glass at the joints of the mold.

Loss of light by passage through globes.

According to Professor Crocker, the loss of light in passing through transparent globes amounts to as much as from five to ten per cent. Unless care is taken, however, to keep the globes clean, this loss may be even more than twice as great. Opal globes may cause a loss varying from twenty per cent to thirty-five per cent, and this, in the case of thick opal globes, many sometimes reach as high as fifty per cent. With alabaster globes the loss is even greater, sometimes amounting to as high as from forty to sixty per cent. Sometimes the upper part of the globe is left clear and the lower part ground. The clear part may either be the upper half

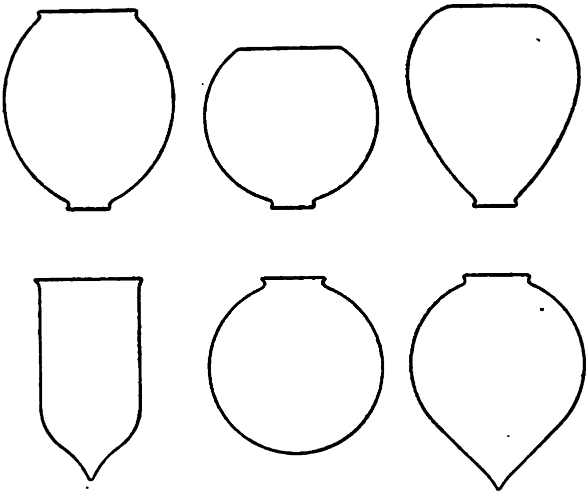


Fig. 117.—Various Shapes of Outer Globes for Arc Lamps. Note that some of the globes are open at both top and bottom, while some are open only at one end.

of the globe, such as, for example, in department stores, where the greater part of the light is to be thrown on the walls and ceiling for diffusion, and the smaller proportion thrown directly downward; or, a vertical half of the globe may be ground, as, for example, in show windows, where the clear half of the globe faces the window, and the ground half is turned toward the observer.

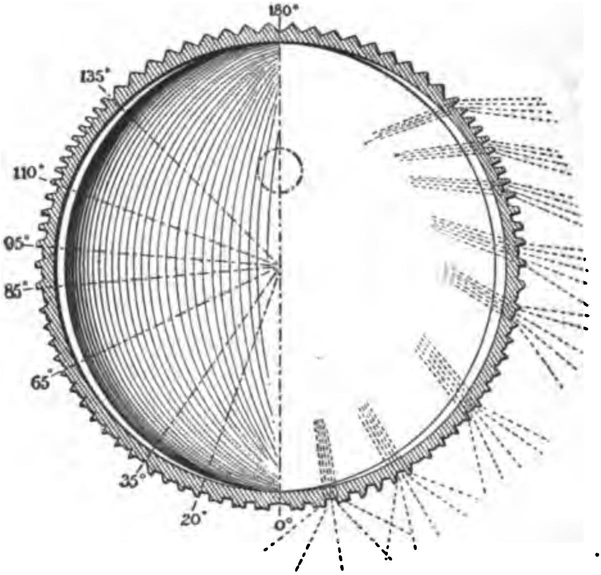


FIG. 118.—"Holophane" for Arc Lamp, a form of outer globe depending on reflection and refraction of the light. Note the fact that this globe acts to throw most of the light downward.

Holophanes. An improved form of glass globe, called the "holophane," ensures an excellent distribution of the light. Here the entire globe is made of clear glass, but the outer surface is molded in the shape of hollow prismatic rings, as shown in Fig. 118. The inclination of the faces of the rings differs in various parts of the globe. They are so arranged that the light striking the upper part of the globe is reflected generally downward, while that striking the remaining rings emerges from the globe either horizontally, or in a direction below the horizontal line. In order to ensure a still better general diffusion of the light, the globe is also ribbed vertically. An objection to the use of the holophane arises from the fact that, for its proper operation, the position of the arc should be maintained constant, or the lamp should be of the focusing type. Lamps of this description are much more difficult to keep in order, and much more expensive than the lamps ordinarily employed.

The objection to the use of holophanes.

CHAPTER XV

FOCUSING LAMPS OR ARC-LIGHT PROJECTORS

> "Lie like a shaft of light across the land
> And like a lane of beams athwart the sea."
> —*The Golden Year:* TENNYSON

Focusing lamps.

FOR purposes where reflectors or lenses are employed to throw the light of the arc in one direction as a more or less parallel beam, it is necessary to maintain the position of the arc despite changes in the length of the carbons due to their consumption. In order to accomplish this it is necessary to feed both the carbons, the positive carbon being fed about twice as rapidly as the negative. Such lamps are called focusing lamps.

Some of the different purposes for which focusing lamps are employed.

Focusing lamps are employed for a great variety of purposes. At sea, for example, they are employed for searchlights for discovering the position of the enemy's ships, detecting the approach of torpedo boats, or for the general illumination of the ocean off dangerous parts of the coast. Focusing lamps are also employed in the illumination of lighthouses, to enable ships to determine their location; in theatres for scenic effects, for projecting lanterns, for electric headlights for locomotives, and for a variety of other purposes.

Since in searchlights it is desired that all the light shall be thrown in one direction only, the carbons are not, as a rule, placed vertically over one another, as in ordinary arc lights, but are inclined away from the direction in which the light is to be projected, so that the rays of maximum intensity shall, on the whole, issue in a more or less horizontal direction. An examination of Fig. 119, at the right-hand side of the figure, will show how inclined carbons expose a greater portion of the positive crater in the general direction in which it is desired that the greatest amount of light shall issue. Sometimes, the same effect is produced by carbons that are placed vertically one over the other, by moving or shifting the positive carbon a little to one side, as shown in Fig. 119, at the left-hand side of the figure. In all cases, however, the rays of light from the displaced carbons are caused to issue from the lamp in a direction approximately parallel, either by reflection from mirrors, or by refraction from lenses, placed back of the arc.

Position of carbons in search-lights.

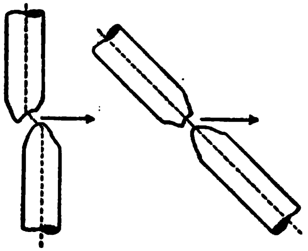


FIG. 119.—Positions of Carbons in Focusing Carbon Arc Lamp. Note that in both of the positions here represented, the light from the highly heated positive crater can be readily thrown out in a general horizontal direction.

High-grade searchlights are generally provided with a lamp mechanism containing both a direct-current or series magnet, and a shunt magnet. Very small focusing lamps are sometimes operated by hand, but this is objectionable, unless the lamps are

Lamp mechanism of searchlight.

to be employed for a very short length of time. A lamp mechanism of the automatic focusing type, such as is employed in searchlights, is shown in Fig. 120. Since the candle-power of the searchlight is high, large carbons are employed, in order to permit an increase in the area of the positive crater that will attend the employment of large currents. The positive and negative carbons are shown respectively at P and N. The direct-current electromagnet, M, by the attraction of its armature, depresses the lever LL, and thus separates the car-

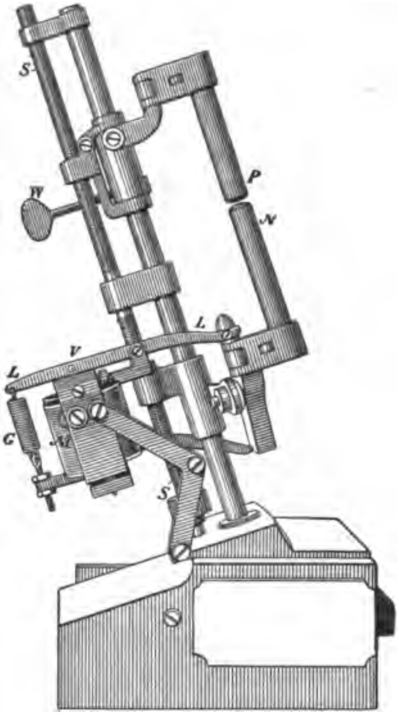


Fig. 120.—Automatic Focusing Arc Lamp for Searchlight. Note the fact that here, as is generally the case with focusing lamps, both carbons are fed.

bons, establishing the arc between them. When this arc becomes too long, a shunt magnet, placed in the base of the lamp mechanism, by the attraction of its armature, permits a screw-shaft, SS, to be driven so as to bring the carbons together. W is a device operated by hand, and provided so as to permit the

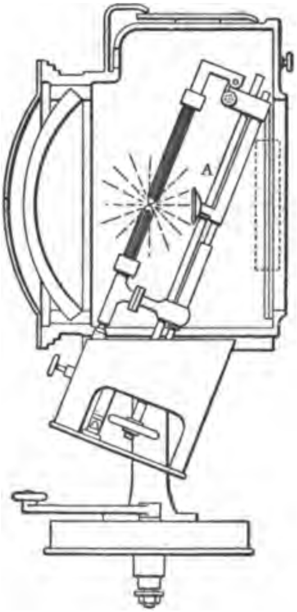


FIG. 121.—Focusing Lamp and Mirror for Searchlight. Note that in this case the light of the arc is directed toward the reflector in the back of the reflector box, and that the light after reflection passes out of the front of the reflector box.

operator to move the positive carbon to-and-fro, so as to expose its crater in the best direction.

Various forms of reflectors used in arc-light projectors.

The lamp mechanism shown in the preceding figure is placed inside a cylindrical projector box, as shown in Fig. 121. In the rear of the box is placed a reflector made of silvered copper or glass. In high-class projectors, this reflector is always made of glass, as is the case in the projector shown in Fig. 121, where a glass reflector, A, has two curved surfaces, which, however, are not parallel to one another, so that the glass is thicker in some places than in others. Since this difference in thickness renders the glass reflector liable to crack, in the highest grade of instruments, it is made in the form of a parabolic glass reflector, coated with silver.

Screen shutters are placed in front of the case to prevent the direct rays from leaving the projector.

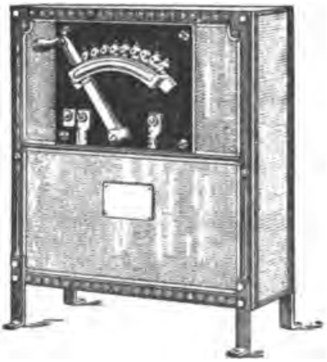


FIG. 122.—Rheostat or Variable Resistance for United States Government form of High-grade Searchlight Projector.

Use of magnet to maintain position of arc.

These shutters throw the rays back on to the reflector, so that all the light issuing from the projector comes out in a nearly parallel beam. In all high-class projectors a magnet surrounds the arc except on one side, so as to ensure the maintenance of the arc in the centre of the large carbons, and, in this way, maintain it at the focus of the reflector. Projectors are generally built to operate on constant-potential mains, such as are employed for feeding incandescent lamps. A regulating resistance, therefore, is placed in series with the lamp, in order to reduce the voltage of the mains to the voltage required for the operation of the projector. This is usually from forty to sixty volts, according to the lamp and the current employed. A form of rheostat, or variable resistance, employed in connec-

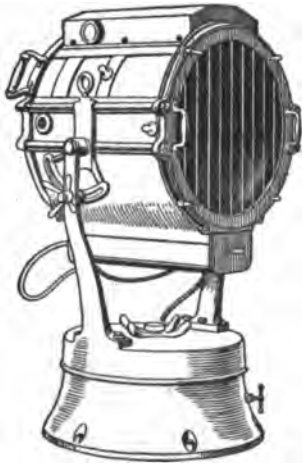


Fig. 123.—General Electric Company's Hand-controlled Searchlight, 24-inch Projector.

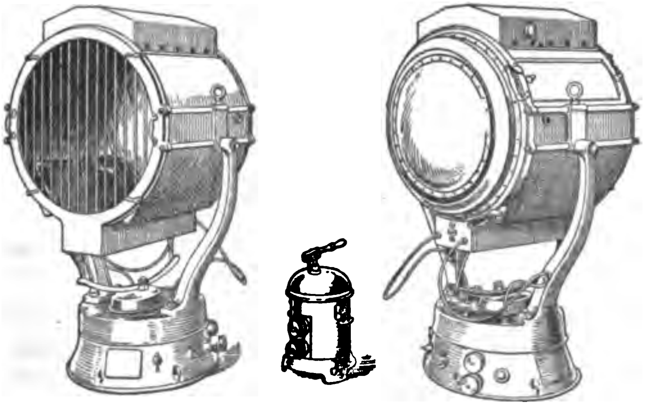


Fig. 124.—General Electric Company's Electrically Controlled Searchlight Projectors, with controller detached.

Rheostat for use of arc-light projectors on constant-potential mains.

tion with a high-grade projector, is shown in Fig. 122. Here the movements of a lever serve to introduce into, or remove from, the circuit a varying number of series-connected German silver resistance coils.

The following are the current strengths and voltages employed by the General Electric Company in

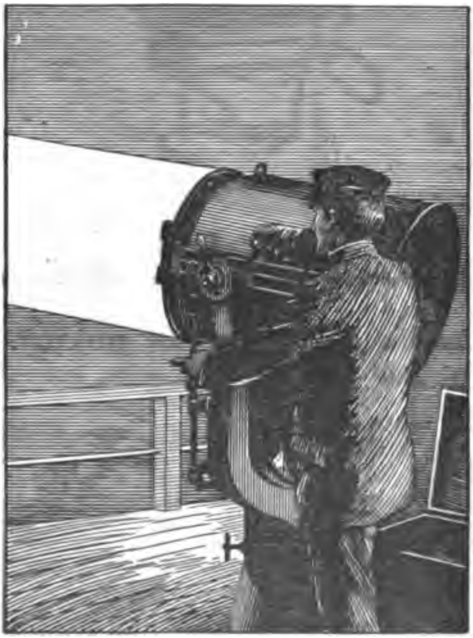


FIG. 125.—30-inch Projector at Work. The nearly parallel beam of light can be directed to different points of the horizon by the attendant.

Current strengths and voltages employed in various sizes projectors.

its various sizes of projectors. The 9-inch projector takes a current of 10 ampères, and requires a pressure of from 43 to 46 volts between the carbons. It employs for the positive carbon a cored carbon ½ inch in diameter, and for the negative a solid carbon $\frac{7}{16}$ths of an inch in diameter. The 18-inch projector requires a current of 35 ampères, and a pressure of from 47 to 50 volts between the carbons. It employs a 13/16ths of an inch positive cored carbon, and a ⅝ths inch negative solid carbon. A 30-inch projector requires 80 ampères with from 49 to 54 volts between the carbons. It employs a 1⅛th inch positive cored carbon, and a ⅞ths inch negative cored carbon. A 36-inch projector requires a current of 130 ampères, and from 50 to 55 volts pressure at the arc. It employs a 1¼-inch positive carbon, and a 1-inch cored carbon.

Current strengths and voltages employed in General Electric Company's arc-light projectors.

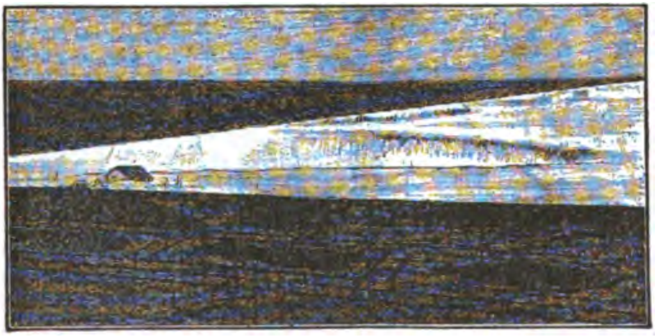


Fig. 126.—Advantage of Slight Divergence of Projector Rays. Niagara under the searchlight. Note the fact that, if the rays were strictly parallel, but a comparatively limited portion of the Falls would be illumined.

The beam of nearly parallel rays, that is projected or thrown out from the projector, can be turned in the various directions required, either by means of hand-control, or by means of electric-control. In a hand-controlled projector of the form shown in Fig. 125, the light can be turned in various vertical or horizontal directions by the operator, standing by the side of the projector case or box, and moving it by the handles in the desired direction. In electrically-controlled projectors, such, for example, as

Methods for throwing search-light beam in different directions.

Hand and electrically controlled projector.

that shown in Fig. 124, these movements are obtained by means of two electric motors placed in the base of the projector. One of these motors drives a train of gear-wheels that controls the vertical movements, and the other motor drives a train of gear-wheels that controls the horizontal movements.

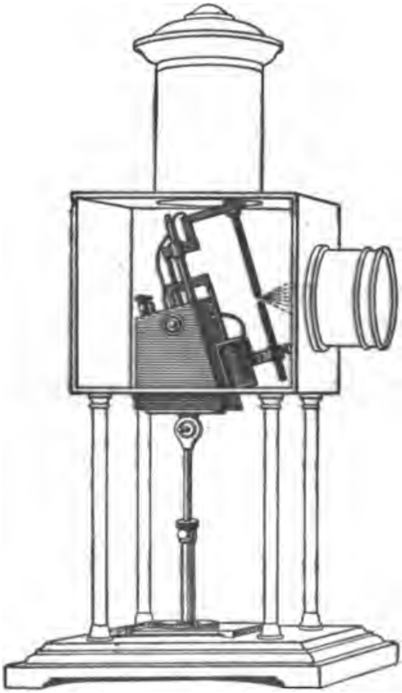


FIG. 127.—Focusing Lamp for Lantern Projection. Note that both carbons are electrically fed. In some forms of focusing lamps, this feeding is accomplished by hand.

These movements are regulated by a controller. Matters are so arranged that the movements of the controller handle correspond to the movements of the beam of light. Directions between the vertical and the horizontal are obtained by the simultaneous movements of the two trains of gear-wheels.

Where the projector is placed on top of the pilot-house, the movements of the beam of light are controlled by means of mechanism placed within the pilot-house.

A 30-inch projector in operation is seen in Fig. 125. Here the issuing rays appear to be parallel. Generally, however, they are given some little divergence, so as to increase the area of the space illumined. For example, in Fig. 126, a slight divergence given to the rays of light permits them to illumine a greater portion of the falls of Niagara than would have been possible had the rays been maintained exactly parallel.

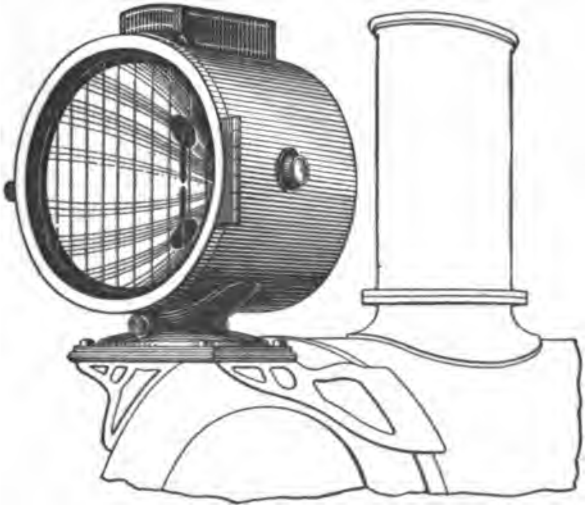


FIG. 128.—Focusing Lamp for Locomotive Headlight.

Advantages of slight divergence of rays from search-light.

The application of a projector for lantern purposes is seen in Fig. 127. The light so obtained

Focusing lamp for lantern.

gives excellent results, both for the ordinary lantern slide, and for the projecting microscope.

Where electricity is employed on railroad trains for incandescent lamps and other purposes, a carbon-arc headlight is sometimes employed. A headlight of this description is shown in Fig. 128, where a focusing arc lamp is placed at the focus of a parabolic reflector.

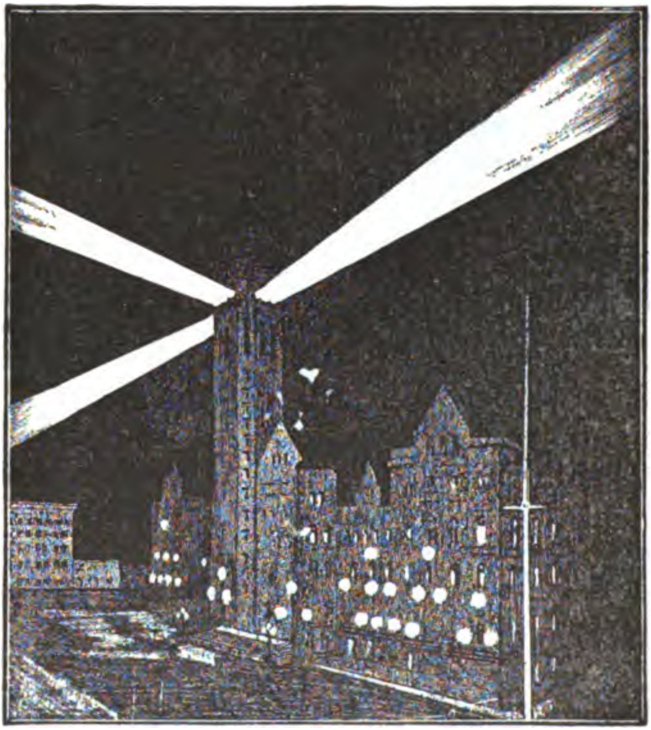


FIG. 129.—Toronto City Hall with Ten 30-inch Projectors.

Focusing lamp for locomotive headlight.

Sometimes, in order to produce very marked

Simultaneous use of several search-lights.

effects, a number of projectors are simultaneously employed. Very beautiful effects of this character were obtained in the illumination of the Toronto City Hall, with ten 30-inch projectors, on the recent occasion of the Duke of York's visit to that city. The general appearance of this is shown in Fig. 129.

CHAPTER XVI

ARC-LIGHT GENERATORS

> "In arc lighting in series, the function of the dynamo is to keep the ampères constant, no matter how many or few lamps are in circuit; while each lamp is provided with a shunt device which governs the movement of the carbons, so that the feeding of them shall keep the length of the arc, and the volts at the terminals of the lamp, approximately constant."—*Dynamo-Electric Machinery:* S. P. THOMPSON

ARC-LIGHT generators are of two types; viz., constant-current generators, and constant-potential generators. These two types of generators are respectively employed for feeding lamps on constant-current circuits, and on constant-potential circuits. In constant-current generators the dynamo must be able to maintain on the line conductors an absolutely constant current, no matter how many lamps, up to the full number the machine is designed to produce, may have been introduced into or removed from the circuit. An increase in the number of lamps on a constant-current circuit, of course, necessitates an increase in the resistance of the line circuit, and, conversely, a decrease in the number of lamps necessitates a decrease in such resistance. If, then, the current strength is to be maintained constant, the generator must be capable of proportionally increasing or decreasing the pressure at the machine terminals. In a constant-potential generator, on the contrary, the machine must be able to maintain a constant pressure, or difference of potential, between the mains, no matter how many lamps have been intro-

Constant-current arc-light generators.

Constant-potential arc-light generators.

duced into the circuit, or no matter how much the current strength may have increased.

At the present day, series arc lamps are placed in a single circuit sometimes to the extent of 125 or more. This requires a very high voltage on the line. As is well known, in generators of the closed-coil type, that is, those in which the armature coils are connected together in a single closed circuit, any sudden breaking or opening of the circuit will result, by self-induction, in the production of a dangerously high voltage, that might readily cause considerable damage, either to the line and its apparatus, or to adjoining property. When a great number of arc lamps are employed in series on the same line where large generators are required, machines of the open-coil type are preferable, that is, machines in which the armature coils are not connected in a single closed circuit; for it has been found by experiment that the sudden breaking or opening of the circuit of an open-coil machine is not attended by the marked increase of potential before referred to. This is, possibly, for the reason that the excessive voltage is discharged or spills over the adjoining commutator segments.

Dangerous increase of pressure on circuit of closed-coil arc-light generators on suddenly opening circuit.

Why open-coil arc-light generators are preferable on long circuits containing many arc lamps.

There are two forms of open-coil dynamos that are now generally employed for obtaining the constant current employed in series arc lighting; viz., the Brush and Thomson-Houston dynamo. A Brush arc-lighting generator, of a size capable of being arranged so as to give a constant current of 9.6 ampères, at a pressure of 6,250 volts, and of then maintaining 125 open arc lamps; or a current of 6.6 ampères, at a pressure of 8,500 volts, and of then maintaining 115 enclosed or 170 open arc lamps; or a current of 5 ampères, at a pressure of 10,000

Brush multi-circuit arc-light generator.

volts, and then maintaining 130 enclosed arc lamps, is shown in Fig. 130. An automatic regulator is employed that permits the machine automatically to maintain the constant pressure on all these lamps, either in a single circuit, or in two or four separate circuits. The method of thus separating a long series circuit, on which a great number of arc lamps are maintained, into a number of separate circuits, has a great advantage in lessening the danger arising from the high-pressure circuits on which arc lamps are required to be frequently handled for recarboning, or cleansing the lamps and globes. Where a number of separate circuits are provided, the generator is called a multi-circuit generator. That shown in the figure before referred to is a four-circuit generator. These four separate circuits are diagrammatically represented at the top of the figure.

Advantages of employing multi-circuit arc-light generator.

The field magnets of the preceding generator consist of eight magnet coils, four on each side of the machine, opposite coils producing poles of the same name. The commutator consists of four separate commutators placed side by side, and provided with four separate sets of brushes. The switch handles, placed above the machine, are intended to control the different circuits. An extra switch is provided to short-circuit the field coils when the machine is out of action. The armature consists of a thoroughly laminated ring core, deeply grooved, separate coils being wound in these grooves. Ample provision is made for the thorough ventilation of the armature. An armature wound with its coils, and mounted on the shaft with its commutator, is shown in Fig. 131. The collecting brushes are made of thin leaf-copper. The mechanical details of the armature are so arranged that, should any armature

Description of Brush multi-circuit arc-light generator.

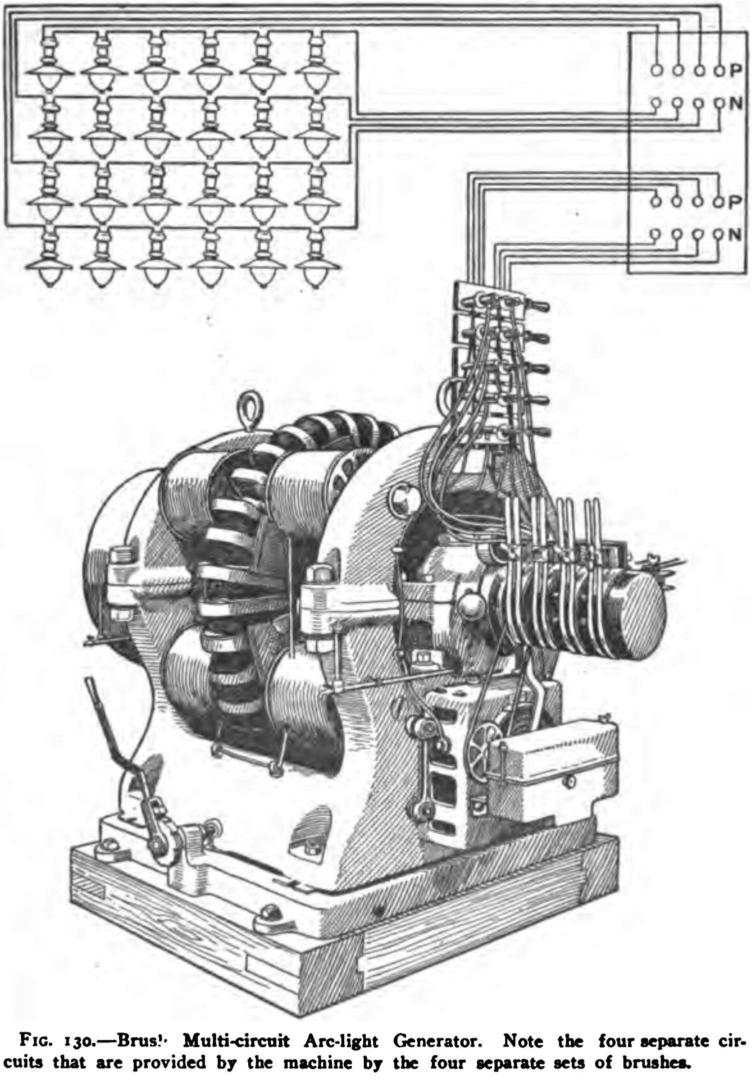


FIG. 130.—Brush Multi-circuit Arc-light Generator. Note the four separate circuits that are provided by the machine by the four separate sets of brushes.

coil be burned out, or otherwise destroyed, it can be rewound without the armature being removed from the machine.

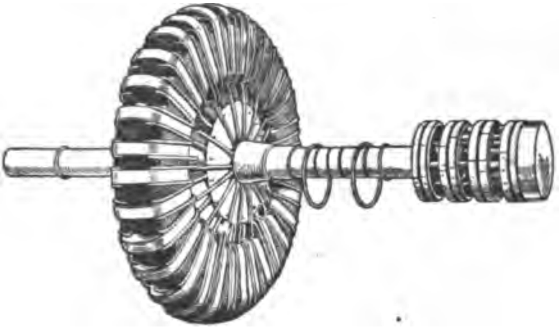


Fig. 131.—Armature and Commutator of Brush Arc-light Generator.

Brush's automatic regulator for arc-light dynamo.

The automatic regulation employed in the Brush machine is shown in Fig. 132. A carbon shunt C, of a variable resistance, is placed across the field magnets F, M. An electro-magnet B, placed in

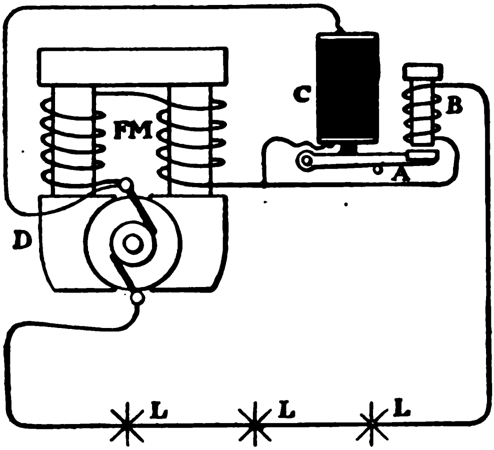


Fig. 132.—Brush's Automatic Regulator for Arc-light Dynamo. Note the nature of the device for electro-magnetically varying the resistance of the pile of carbon plates C by pressure.

series with the main circuit, on the attraction of its armature, reduces the resistance of the carbon plates C, by pressing them together when the current becomes stronger. This decrease in the resistance shunts a part of the current from the field, and thus weakens the field. This regulator is able to maintain a constant current strength, even when the speed of rotation varies. For larger sizes of machines another form of regulator is employed. Such a form of automatic regulator is shown in Fig. 133.

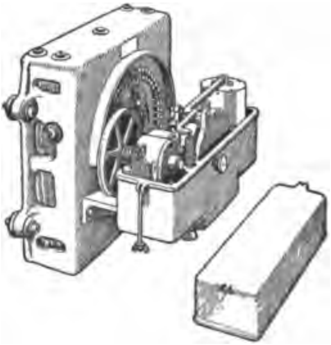


FIG. 133.—Automatic Regulator for Brush's Multi-circuit Generator.

Thomson-Houston arc-light dynamo.

A Thomson-Houston dynamo electric machine, shown in Fig. 134, employs a drum-wound armature, which, when completed, has a nearly spherical form. Its winding consists of three sets of coils only. One terminal of each coil is connected to a common point, and the other terminals are connected to the segments of a three-part commutator. These commutator segments are insulated by means of an air space between adjoining segments. Two brushes are placed on opposite sides of the commutator, each brush being formed of two separate brushes connected together. During the rotation of this armature in the bipolar field produced by the field coils C and C', during certain parts of the rotation two armature coils are connected in series, while during other parts of the rotation, two armature coils in parallel are connected with the remaining coils in series. Since machines of this type produce an E.M.F. of 3,000 volts and over, at adjoining commutator segments, in order to prevent the flashing or arcing that might otherwise occur, an air blast, obtained from a centrifugal blower, is directed against the commutator segments, so as to extinguish such arcs.

Thomson-Houston air-blast.

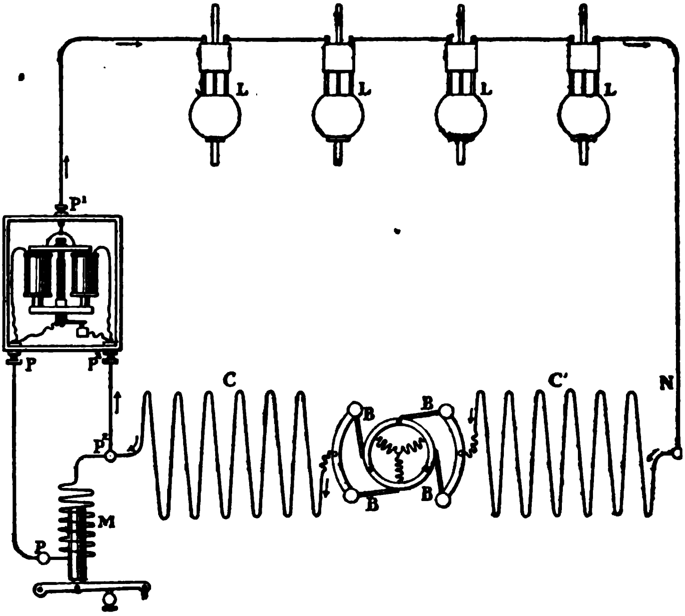


FIG. 134.—Diagram of Circuit Connections of Thomson-Houston Arc-light Dynamo and Regulator. The connection between the armature of the regulating magnet and the brushes is not shown.

In the Thomson-Houston machine the current strength is maintained constant by means of an automatic regulator, also shown in Fig. 134. This regulator consists of a wall-controller and a regulating magnet. In the wall-controller two solenoidal coils, represented at the upper left-hand corner of the figure, are connected in series with the main circuit. When the current strength becomes excessive, these coils attract their cores, open a shunt circuit P_1 P_2, and cause the main current to pass through the coils of the regulating magnet M. This magnet, attracting its armature, shifts the position of the collecting brushes on the commutator, and thus restores a normal current strength. During this shifting, the distance between the positive and negative brushes is lessened, thus resulting in a corresponding decrease in the E.M.F. produced. Sometimes, instead of employing an almost spherical armature from a drum-wound core, a ring-wound armature is employed, such as is shown in Fig. 135.

Thomson-Houston automatic regulator for arc-light generator.

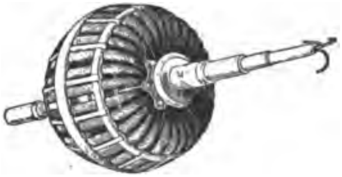


FIG. 135.—Ring-wound Armature of Thomson-Houston Dynamo.

Thomson-Houston ring-wound armature.

A Thomson-Houston arc-light dynamo is shown in Fig. 136. The regulating magnet is seen at the upper left-hand corner of the figure. Machines of this type are capable of producing currents of 6.6 ampères, for 1,200 nominal candle-power lamps, and 9.6 ampères, for 2,000 nominal candle-power lamps. For the former, distance between the carbons should be from 1-32 to 1-10 of an inch, and for the latter from 3-32 to 1-8 of an inch.

Thomson-Houston arc-light dynamo.

The constant electric pressure required for the operation of a number of arc lamps connected in multiple with constant-potential mains, is generally obtained by means of compound-wound generators, the field magnets of which are wound with both series and shunt coils, as has already been explained. Where it is required to maintain a constant-potential at some distant point in a long circuit, the machine is over-compounded by increasing the number of series-windings on the field magnets.

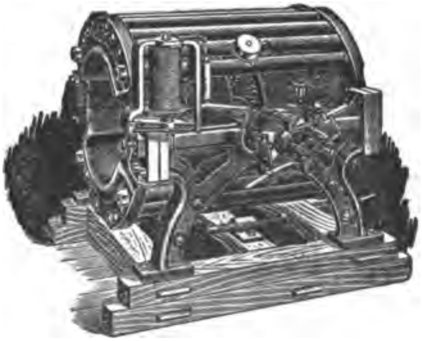


FIG. 136.—Thomson-Houston Arc-light Dynamo.

Compound wound arc-light generators.

For feeding lamps on alternating-current circuits, various alternators are employed. Where constant-current circuits are to be maintained, the constant-current transformer already described is employed. Where constant-potential circuits are to be maintained, some form of constant-potential alternating-generator is employed. In some cases constant-current alternators are employed in which no regulators are used, the machine being so designed that the current strength does not greatly increase, even if the machine is momentarily short-circuited.

Use of some form of safety cut-out.

In order to avoid injury to the insulation from the increased voltage that occurs, when the circuit is suddenly opened, some form of safety cut-out is employed. When constant-current transformers are employed, their primaries are generally supplied in parallel from constant-potential mains.

CHAPTER XVII

EARLY HISTORY OF THE INCANDESCENT LAMP

> "In its most modern form, the electric incandescent lamp always has been, and always will be, inseparably associated with the names of Mr. Thomas Alva Edison and Mr. Joseph Wilson Swan, and in a lower, though by no means negligible, degree with those of Mr. Lane-Fox and Messrs. Sawyer and Mann."—*Lecture*, 1894: J. A. Fleming

Difference between the luminous portions of arc and incandescent lamps.

IN the electric arc lamp the light is produced by the passage of the current through a mass of glowing carbon vapor, that fills the space between the positive and the negative carbons. Here a movable electric conductor is raised to a high temperature, the circuit being at the highest temperature at its ends, where it abuts on the positive and negative carbons. In the incandescent electric lamp, on the contrary, the light is obtained solely by the incandescence of a continuous conductor, raised to a high temperature by the passage of the current through it. This conductor may be formed either of various metallic substances, or of carbon. In the early history of the incandescent electric lamp, various conductors made of platinum, iridium, and alloys of these metals, were employed. At the present time practically all electric incandescent lamps are made of slender threads or filaments of carbon.

As early as the time of the invention of the Leyden jar, it was found that the discharge of a Leyden-jar battery through thin metallic wires not only raised such wires to bright incandescence, but even deflagrated or volatilized them. During these deflagrations, there were momentary flashes of light produced that were due to voltaic arcs formed by the volatilizing of the metal on the rupturing of the circuit. Where, however, the wires were fairly thick, the discharge only produced light by incandescence. In this connection it may be mentioned that Van Marum, whom we have already referred to as having produced a very large frictional electric machine, succeeded in raising wires of platinum and other metals to a high incandescence by the discharge of his machine. These experiments were repeated by the discharge of the electric currents produced by voltaic batteries. In all of these experiments, we may find the early germs of the incandescent electric lamp, although, of course, in impracticable forms.

Arc and incandescent light produced by deflagration of metallic wires by Leyden battery discharges.

Van Marum's incandescing metallic conductors.

Davy, to whom we have already referred in connection with the history of the carbon voltaic arc, succeeded, by the use of voltaic batteries capable of producing powerful currents, in raising the temperature of wires of iron, silver, gold, and platinum, to high electric incandescence. Perhaps one of the nearest approaches to a metallic incandescent electric lamp was made by Children, who, by means of the current obtained from a large voltaic battery, succeeded in raising the temperature of a fairly thick and long platinum wire to bright incandescence. These experiments were conducted by means of the apparatus shown in Fig. 137, where the various wires to be heated by the passage of the electric current were connected to two upright metallic rods. In order to prevent the wires from being all raised to incandescence at the same time, one end of each wire was insulated, so that the

Davy's and Children's experiments in incandescence of metallic conductors.

battery terminals could be applied successively to the different wires. Such an apparatus only needed to be covered by a glass globe, in order to protect the wires from the action of the oxygen of the air, and of draughts of air while at the high incandescing temperature, to produce an early variety of the incandescent lamp.

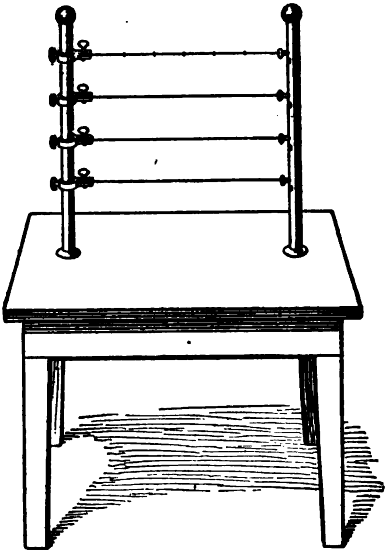


Fig. 137.—Children's Experiments on Incandescence of Metallic Wires. An early form of apparatus in which metallic wires were rendered incandescent by the passage of electric currents.

About the same time, Wollaston, who had succeeded in obtaining a very fine platinum wire some $\frac{1}{2,800}$ of an inch in diameter, raised a piece of this wire to bright incandescence by the current obtained from a single voltaic cell, whose elements consisted of copper and zinc. Wollaston obtained this very thin wire as follows: he coated a fine

Wollaston's miniature electric incandescent lamp.

How Wollaston obtained extremely fine platinum wire.

platinum wire with a covering of silver, and then, placing this compound wire in a draw-plate, he drew it out into a great length of very fine wire, which consisted of a still thinner wire of platinum on the inside, coated on the outside with silver. By immersing this silver-platinum wire in strong nitric acid, he dissolved off the coating of silver, and thus obtained the thin platinum wire. By the same means Wollaston obtained a still finer platinum wire, for use in the spider lines, or wires of telescopes, to replace the delicate spider threads. In this way he formed a platinum wire of the surpassing thinness of the $\frac{1}{30,000}$ of an inch in diameter.

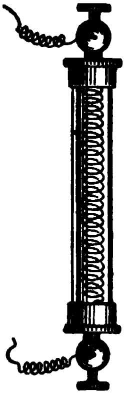


FIG. 138.—De la Rue's Enclosed Incandescing Metallic Wire. Note the fact that this form of incandescing metallic wire gave more light both because of its spiral form and from the fact of its being enclosed.

De la Rue's enclosed incandescing metallic wire.

A still nearer approach to the incandescent electric lamp was reached when the wire to be rendered incandescent by the passage of the current was placed, as shown in Fig. 138, within a glass enclosing vessel, by means of which it might be protected from the air. Such a vessel was employed by De la Rue, and others, in their experiments on incandescent wires.

Grove's experiments on effect of gases on temperature of glowing wires.

As early as 1845, Grove discovered that the quantity of light emitted by an incandescent platinum wire varies greatly with the character and condition of the gas surrounding the glowing platinum.

Various attempts were made to practically employ the incandescence of metallic wires for the production of light for artificial illumination. It was soon seen to be necessary to enclose such wires in glass globes, from which the air had been removed; for, when they were exposed to the air, they were soon wasted away, generally by oxidation, and were rapidly cooled by the surrounding air. One of the earliest attempts with a lamp of this type was that made by Frederick de Moleyns, who, in 1841, took out a patent in England for an incandescent electric lamp, consisting of a coil of plati-

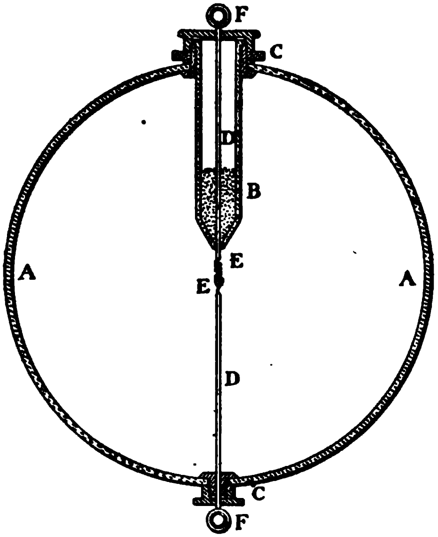


Fig. 139.—De Moleyn's Incandescent Electric Lamp. Note the fact that this early form of lamp employed both the incandescence of platinum wire and carbon.

De Moleyn's early incandescent electric lamp.

num wire, EE, Fig. 139, placed inside a glass globe, AA, from which all the air had been exhausted. The electric current was led into the lamp globe by means of conductors D and D, passing into the lamp chamber through the walls of the globe. De Moleyns' early form of lamp did not, however, depend on the incandescence of the platinum wire only. The conductor D, in the upper part of the lamp chamber, passed through a hollow conically-shaped vessel, that was filled with powdered lamp-black or charcoal. When the platinum wire was rendered incandescent by the passage of the current, the powdered charcoal was allowed to fall by gravity on the coils of the platinum wire, and was thus rendered incandescent, greatly increasing the amount of light produced. Although a lamp of the De Moleyns' type would not be practicable, owing to the irregularities in its action, and to the difficulty of maintaining the transparency of the lamp chamber, yet it is to be regarded as a fair beginning in the art of electric incandescent lamps.

De Moleyn's use of powdered charcoal in his incandescent lamp.

An American named J. W. Starr has the honor of being the first to employ carbon alone in a vacuous space for an incandescent electric lamp. Starr was associated with Edward A. King, an Englishman, who took out a patent in England, in 1845, in his own name. This has led some to mistake King for the true inventor of the carbon incandescent lamp, so that the lamp sometimes goes after his name. It is also frequently called the Starr-King lamp. This lamp was publicly exhibited in England, where a candelabra, with 26 of the Starr-King lamps representing the 26 of the United States that were then in the Union, gave satisfactory results. The distinguished Faraday, who saw it, was much pleased with its operation. Unfortunately, Starr, shortly

Important invention of Edward A. King.

The Starr-King incandescent carbon lamp.

after this exhibition, sailed for America, and died on the voyage. His untimely death seems to have put a stop to its commercial development.

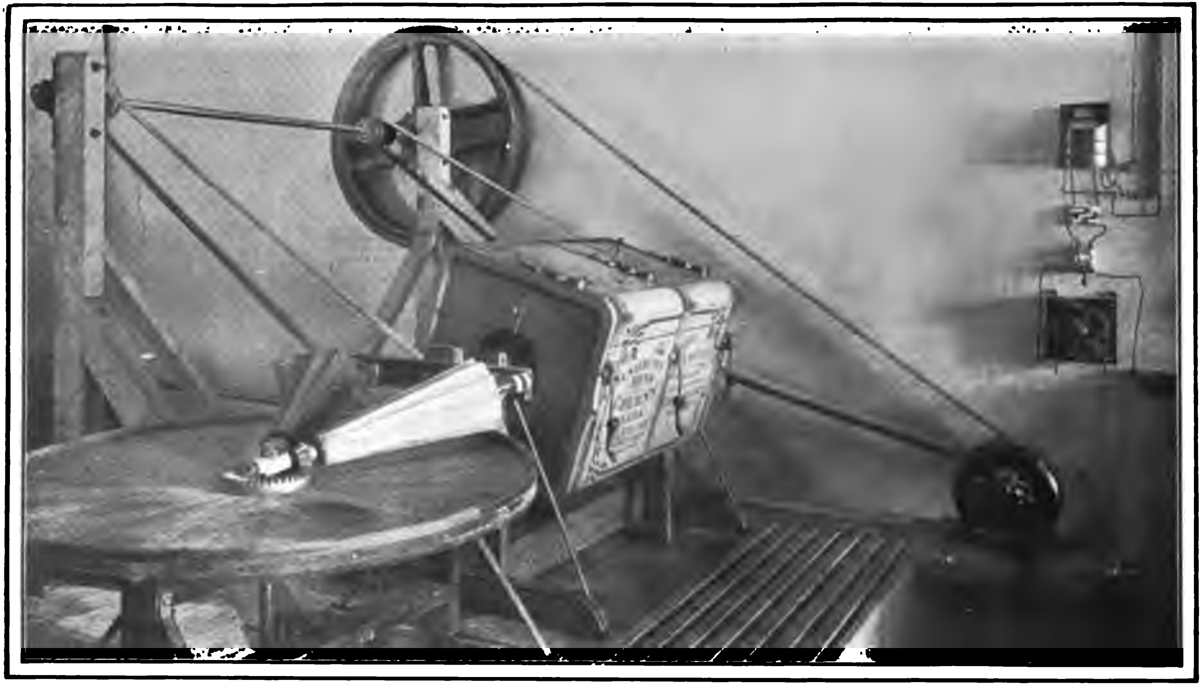
The Starr-King lamp employed rods of incandescent carbon, placed in a glass vessel, in which the high vacuum, known as the Torricellian vacuum, existed. In the specification of the British patent the invention is thus described:

Language of specification of Starr-King patent.

"The nature of the invention consists in the application of continuous metallic and carbon conductors, intensely heated by the passage of a current of electricity for purposes of illumination. The metal found to be the most advantageous to use for the purpose is that which, while it requires a very high temperature for its fusion, has but a feeble affinity for oxygen, and offers a great resistance to the passage of an electric current."

The inventor proposed to employ platinum or carbon. The construction of the Starr-King carbon lamp will be understood from an examination of Fig. 140. A glass tube, B, similar to those employed in barometers, forms the upper part of a barometer tube, and has a Torricellian vacuum produced in it in the usual manner. This, as is well known, is a fairly high vacuum. A is a piece of gas-retort carbon that is to be rendered incandescent by the passage of the current. The current is passed through the lamp through the conductors D and C, the column of mercury in the barometer tube acting as a part of the path of the circuit. This invention of Starr discloses a remarkable knowledge of the subject, considering the early date of the invention. As already stated, Starr's untimely death checked its commercial development. It would, however, have been impossible to success-

Starr-King lamp too early to be commercially successful.



ELECTRICITY IN THE DAIRY

The large churn here shown is made to rotate rapidly by belting from the small electric motor on the floor

fully place the incandescent electric lamp in everyday use with no cheaper or more reliable electric source than those which existed at this date, so shortly after the invention of the dynamo.

In 1846, William Greener and William Edwards Staite took out a patent in England for "Effecting the illumination of public and private buildings, streets, squares, and other public places, by means of solid prisms or cylinders of carbon, enclosed in air-tight vessels of glass or some other transparent substance, and ignited or rendered luminous by currents of voltaic or magnetic electricity, such carbon being previously freed from the impurities with which it is ordinarily combined. This lamp

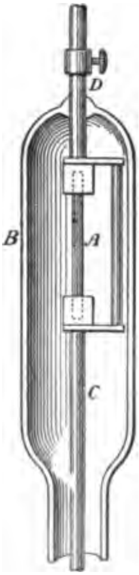


Fig. 140.—The Starr-King Incandescent Lamp, in which carbon was employed. The portion rendered incandescent by the passage of the electric current is the carbon rod A.

Greener and Staite's carbon incandescent lamp.

in many respects closely resembled the Starr-King lamp.

Staite's incandescent electric lamp with platinum-iridium alloys.

In 1848, Staite, one of the inventors of the preceding lamp, invented an incandescent electric lamp, in which strips of iridium, or alloys of iridium and platinum, were enclosed in glass globes, for the purpose of preventing loss of heat by radiation, and thus increasing the temperature of the glowing strips, and, consequently, their light-emitting power. Various forms were given to these electrodes. In the lamp shown in Fig. 141, the glowing conductor was made in the shape of a horseshoe, and placed in an enclosing globe of the shape shown. A triple burner lamp was also formed, as shown in Fig. 142. The inventor describes this latter lamp as follows:

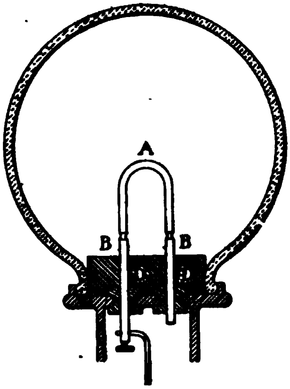


FIG. 141.—Staite's Platinum-Iridium Incandescent Lamp. Note this early use of the horseshoe incandescing conductor. This shape avoids the formation of shadows when the lamp is suspended, as in practice.

Staite's triple-burner lamp.

"Fig. 26 [our Fig. 142] represents a triple electrode suspending lamp. Each electrode is independent of the others, and insulated as before. A battery for working this lamp is divided into three parts, one for each electrode. One wire for the return current (which may be fixed to the lamp or any part of the metallic tube by which it is suspended) is sufficient for all three electrodes, but each electrode is rendered luminous by completing the circuit of that particular electrode, as before described."

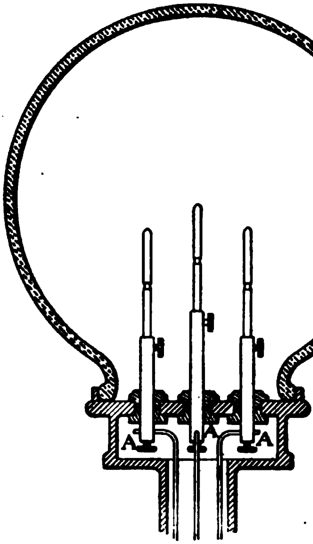


Fig. 142.—Staite's Triple Burner Incandescent Electric Lamp. Here the horseshoe-shaped conductors were employed.

In 1850, Floris Nollet invented a form of incandescent lamp in which the light was obtained by the incandescence of charcoal, placed inside a globe of glass, and roughened on the inside, in order to disperse the light and soften its intensity. A vacuum was maintained in the globe. Nollet's lamp was, in reality, a species of semi-incandescent lamp. Here a conductor, formed of a slender pencil of charcoal, was rendered incandescent by the passage of the current through it; but the greatest proportion of light was that emitted at the end of such pencil, where it was pressed against a cone of char-

Nollet's early form of semi-incandescent electric lamp.

coal. The general arrangement of Nollet's early form of lamp is shown in Fig. 143. Nollet thus describes this part of his invention:

"When it is desired to light by means of the incandescence of charcoal, I employ an arrangement of apparatus similar to that which is represented in Fig. 10 [our Fig. 143]. A is a globe of glass, which may, if desired, be ground or obscured on the inside, in order to disperse and soften the intensity of the light. The stopper B of this globe is very carefully luted, and two insulated polar wires, P and N, of about two millimetres in diameter, are passed through it. One of these wires is soldered to the side, and toward the upper end of a copper tube C, of about one decimetre (about four inches) in length. This tube is intended to hold a little cylinder of charcoal, which is kept constantly pushed down from above by a small cylinder of lead, which is of a weight adjusted to the purpose. The other polar wire comes out under the lower end of this tube at about one centimetre (about four-tenths of an inch)

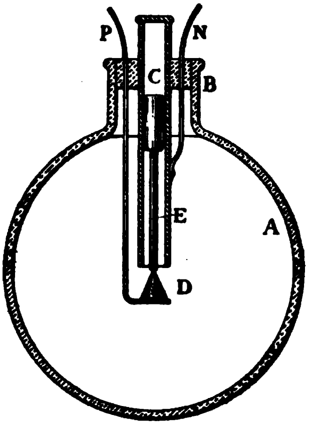


FIG. 143.—Nollet's Early Form of Semi-incandescent Electric Lamp.

Movable carbon.

distance from its extremity, and terminates in a little cone D, of prepared charcoal or coke, and against the top of which the little charcoal cylinder E rests, which, when the current is established, becomes incandescent, and remains in that state a very long time, because the small portions which are consumed are continually replaced by a portion of the cylinder which the metal presser forces on to the top of the cone. A tube of glass, or other suitable substance, also passes through the stopper, and admits of its being connected to the pneumatic receiver in order to create a vacuum in the globe. The tube is afterward cut and hermetically sealed, in order to prevent the re-entry of air."

Nollet's description of his lamp.

Another lamp in which incandescent carbons were placed in a vacuous glass globe was invented by Martyn John Roberts. The incandescent carbon was made of "a piece of very thin graphite, about ½ an inch long, and ⅛ an inch wide, and as thin as conveniently can be made." In order to increase the brilliancy of the light by means of an increase in temperature, Roberts placed a piece of lime, so that it could be heated by the glowing conductor. Roberts thus describes his invention:

Roberts's incandescent lamp.

"I have discovered that flame, or the combustion or volatilization of some substances between or on the points of the electrodes, will very much increase the light produced by an electric lamp. Thus, if a candle or lamp be placed so that its flame shall pass between the points of the electrodes, the brilliancy of the light evolved between the electrodes will be increased; and if lime or any other alkaline earth be interposed between the points of the electrodes when the lamp is in action, the brilliancy of the light evolved will be very greatly increased. When I intend lime to be interposed between the

Roberts's description of his incandescent lamp.

electrodes in this manner, I prefer to effect that object in the same manner as lime is introduced between two jets in what is usually called the Drummond light. I prefer, however, to produce the same, or nearly the same, effect by a new description of electrode, which I make by mixing the material of which the electrodes may be composed with a portion of lime or other alkaline earth (I have used about five per cent of lime with success), taking care not to introduce as much as will materially diminish the power of the electrodes to conduct electricity."

Uses lime to increase amount of light given off.

In 1856, John Thomas Way invented a very curious form of incandescent lamp, in which mercury was permitted to flow in a slender stream through orifices, so as to fall either on a steel point, or on the surface of a mass of mercury. The passage of the current volatilized and deflagrated the mercury, which formed the source of light. This lamp was surrounded by a glass globe, in order to prevent the escape of the poisonous mercury fumes. It is hardly necessary to say that this form of lamp was not successful.

Way's mercury lamp.

It was about 1857 that considerable excitement was aroused in France by an announcement made to the French Academy of Sciences, by Jobard, the director of the Industrial Museum of Belgium, that a person named De Changy had solved the problem of successfully dividing the electric light, and had obtained from a battery of twelve Bunsen cells twelve incandescent lamps of great steadiness, that were entirely independent of one another. De Changy's lamp is shown in Fig. 144. This lamp employed a platinum spiral, enclosed in a glass globe, in which a vacuous space was maintained. There is nothing in this lamp that would seem to

The De Changy electric lamp.

warrant the extravagant statements that were made concerning its success, nor does it seem to have been employed to any extent. A somewhat similar lamp was patented in the United States, in 1858, by Samuel Gardiner and Levi Blossom, of New York City. This lamp consisted of a signal lantern, in which a coil of platinum wire, placed inside the lantern, was rendered incandescent by the passage of an electric current.

The Gardiner and Blossom lamp.

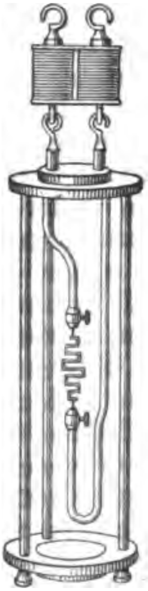


Fig. 144.—De Changy Electric Lamp.

In 1862, Morris, Weare and Monckton took out an English patent for an electric lamp, in which an attempt was made to obtain light for purposes of illumination by means of the passage of electric discharges through vacuum tubes containing vapors

An early vacuum-tube lamp.

or gases. The following description is given of this invention:

"The vapor or gas used is then to be exhausted from the tube till a proper vacuum is obtained to permit the electricity to flow freely from points of platinum or other wires at each end of the tubes and within them. The tubes are then to be hermetically sealed, when they will continue constant in their action, and variously-colored lights will also be produced by the passage of electricity through them. The tubes or vessels may be furnished with glass letters of various colors fixed thereon, or entire words and sentences, in order to afford signals. By causing the electric current (by preference produced and induced by means of our batteries and induction coils) to pass through the tubes in one direction we produce a light or lights of a certain color or colors, and by reversing or otherwise changing the direction of the current, we produce a light or lights of a different color or colors. By a suitable arrangement with regard to the production and repetition of these various colored lights in the tube or tubes or vessels, a code of letters, words, or signals may be established, and submarine, aërial, or underground telegraphic communication effected. The necessary electricity may be obtained from the magneto-electric machine and other sources, but we prefer to employ a voltaic battery with an induction coil. The electric current may be conveyed to and from the apparatus by means of submarine or other wires or cables, according to circumstances."

Morris, Weare and Monckton's description of their vacuum-tube lamp.

From 1862 until 1872, the failures of previous inventors to produce any commercially successful incandescent lamp appear to have discouraged any further attempts until 1872, when a Russian physicist named Ladiguine again took up the problem and made a carbon lamp that gave such promise of success that he was awarded a prize by the St. Petersburg Academy of Sciences.

Prize awarded to Ladiguine for a carbon incandescent lamp.

Ladiguine's English patent on this lamp is dated December 16, 1872, and is taken out, as is not uncommon in English practice, in another name; viz., that of Stanislas Konn. Ladiguine's invention is thus described:

"One or more of the conductors, which are preferably of graphite, are enclosed in a species of lantern hermetically closed and filled with nitrogen or other gas that does not support combustion, and are maintained therein by any convenient method of support. To produce the electric current an ordinary magneto-electric machine, such as those of Wilde, Noble, and others, is employed, and the current is led into the lantern by means of a wire to one of the graphite conductors (when the lantern contains more than one), and in passing through the conductor the electricity heats it to redness, and causes it to give out a brilliant light. The current is then led to the second graphite conductor, and passing through that, producing a similar effect, is led to a third, and so on until all the conductors in the particular lamp have been illuminated, when the current is led to those in the next lamp, and so on to the end of the series, which may consist of hundreds of conductors or lamps."

Konn's description of Ladiguine's lamp.

One form of Ladiguine's lamp is shown in Fig. 145. Here the carbon is employed in a V-shaped piece *b*. The electric current passes down one side of the V and up the other side, by means of the conductors *d, d*. The globe *f* is filled with nitrogen gas, or other gas incapable of supporting combustion.

In awarding to Ladiguine the prize of the St. Petersburg Academy of Sciences, above mentioned, the Russian physicist, Wilde, thus refers to the advantages to be derived from the use of carbon for the incandescent conductors of electric lamps:

Wilde on the advantages of carbon for incandescing conductors.

"Carbon has at equal temperature a greater radiating power than platinum, its thermal capacity is much smaller, so that the same amount of heat raises a carbon filament to a much higher temperature than a platinum wire. Moreover, the electrical resistance of carbon is about 250 times greater than that of platinum: the carbon may therefore be made larger while raising the temperature as much as the metal. Finally, carbon is infusible, and its temperature may be raised without any danger of fusion."

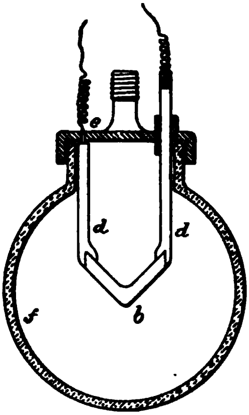


FIG. 145.—Ladiguine Carbon Incandescent Lamp. Note here again the horseshoe form of incandescing conductor, thus avoiding shadows in the space below the lamp.

Ladiguine's invention was brought to Paris by Stephan Kosloff, another Russian, who made some improvements in the construction and operation of the lamp, and took out a patent for the same. Among other improvements, Kosloff introduced a method of rarefying the gas in the globe by the heat of the incandescing carbon. The expanding gas passed through a valve placed in the globe, which valve was afterward kept closed by the pressure of the atmosphere. The small quantity of oxygen in the air remaining in the globe was soon converted into an oxide of carbon, by combining with a part of the carbon. Neither Ladiguine's nor Kosloff's lamp attained much success.

Kosloff's improvements on Ladiguine's lamp.

A weak point in the construction of many of the early incandescent electric lamps was where the copper or other wires inside the lamp globe led the current into the glowing carbon. The wires tended to become so hot at these points that they were frequently melted. Kosloff, like other inventors, avoided this difficulty by greatly increasing the diameter of the carbon at the ends where it was connected.

Kosloff's method of joining leading-in wires to carbon conductors.

A carbon incandescent electric lamp, very similar to that of Ladiguine and Kosloff, was invented in 1875, by another Russian, named Stanislas Konn. In all these early forms of carbon incandescent electric lamp, where a powerful current was passed through the carbons in order to obtain a very high incandescence, and, consequently, great intensity of light, the carbons were rapidly consumed. In some of the lamps already described, a number of separate carbons were placed in the same lamp chamber, so connected that when one rod was consumed the current was automatically passed through another rod. Konn's lamps contained this feature, as will be seen from an examination of Fig. 146, where two separate carbon rods E are placed between the ter-

Konn's multi-carbon incandescent lamp.

Mechanism of the Konn multi-carbon lamp.

minals F and D. It will be noticed that these rods are of greater area of cross-section at their ends, O, O, in order to prevent the great heat of the carbons at E from melting or otherwise destroying the conductors F and D. The enclosing glass vessel B is made air-tight at its base A, by being screwed against a rubber washer, and is exhausted through the tube K. The terminals of the lamp are at N, and at a binding screw connected with A, which passes through an insulating tube in the lamp base. When the carbon rod E is consumed, a metallic bar I, shown in the figure as resting on F, falls into contact with the metallic rod connected with the upper end of the second carbon, shown on the left of E.

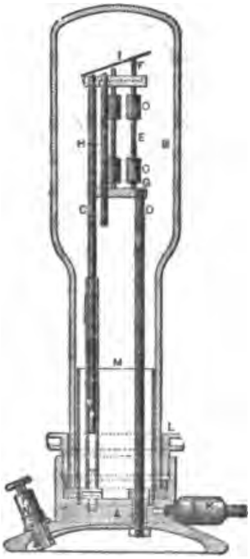


FIG. 146.—Konn's Multi-carbon Incandescent Lamp. Note the means employed for automatically transferring the current from one carbon rod when consumed to the other.

Another method of prolonging the life of a carbon incandescent lamp was invented in 1876, by Boulyguine. Here a long slender carbon pencil was automatically fed, as it was gradually consumed, against a thick piece of carbon. This movement was obtained by the action of weights. The general appearance of the lamp is seen in Fig. 147.

Boulyguine's invention for prolonging the life of a carbon incandescent lamp.

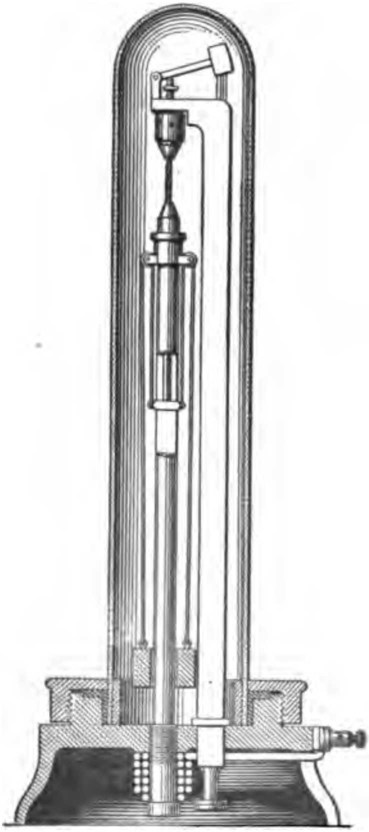


FIG. 147.—Boulyguine's Continuous Carbon Feed Incandescent Lamp.

In addition to the early work done by Starr on the carbon incandescent lamp, very important work was accomplished between 1878 and 1879, and afterward by four American inventors, to whose work we must give some little attention before closing this exceedingly brief history of the early state of the arc.

Four distinguished workers on incandescent lamps.

In 1879, Moses Farmer, of the United States Naval Station at Newport, produced the form of lamp shown in Fig. 148, where a thin strip of carbon is suitably supported inside an exhausted glass globe, between two large metallic blocks, the leading-in wires passing into the lamp through insulated tubes placed in the lamp base. Farmer lighted a private residence at Newport with 42 lamps of his construction.

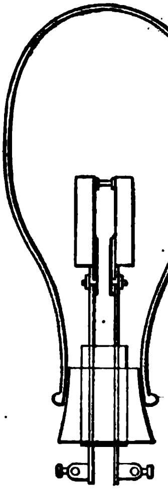


FIG. 148.—Farmer's Incandescent Electric Lamp.

Sawyer-Mann electric lamp.

About the same time, two other Americans, William Sawyer and Albon Mann, produced a carbon lamp in which an incandescing conductor was placed inside a globe filled with nitrogen gas. As in the

Ladiguine and Konn lamps, as that portion of the carbon pencil which is rendered incandescent by the passage of the current was gradually consumed, it was replaced by a fresh portion of the carbon, pressed upward against a contact block of carbon placed in the upper part of the lamp chamber. The general construction of this form of lamp is shown in Fig. 149. The leading-in wire was made of heavy conductors bent as shown to ensure extended radiating surfaces. The lamp chamber was sufficiently long to permit of the employment of a carbon pencil 8 inches in length. In 1880, Sawyer and Mann took

Its similarity to the Ladiguine and Konn lamps.

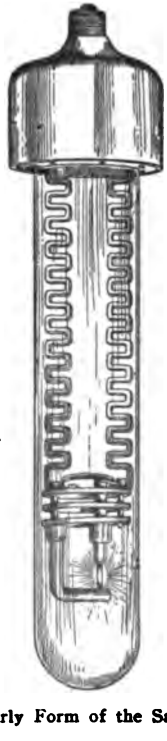


Fig. 149.—An Early Form of the Sawyer-Mann Lamp.

out a patent for a lamp in which a structural carbon, *i.e.*, a carbon made from a carbonized material possessing a definite structure prior to its carbonization, was employed.

Edison's early work on the incandescent electric lamp.

Another American who took up the problem of the incandescent electric lamp at about this time was one who, probably, more than any other single man, made it a commercial success. This was Thomas A. Edison, known all over the world not only for his great genius, but also for his untiring perseverance in any field of practical research. Edison's first attempts were made with lamps in which various forms of platinum and other metallic wires were employed. Like other inventors, Edison made his platinum conductors in the shape of spirals, since, as is very well known, the loss of heat is much less in the form of a close spiral than with the same length of wire in the form of a straight conductor. This may be readily shown by sending a current through a platinum spiral until bright incandescence is reached, and then slowly drawing the spiral out into the form of a straight wire, when the greater loss of heat will cause such a lowering of the temperature that, instead of shining with bright incandescence, the wire will now have only a reddish glow. Edison did not achieve any success in this form of lamp. Difficulties arose from the short life of the lamps when sufficient current was sent through the spirals to produce high incandescence. During these investigations, Edison greatly increased the safe temperature to which such lamps could be exposed, by previously treating the platinum. This treatment consisted in subjecting the platinum to prolonged heating in a vacuous space, so as to drive off the air absorbed by it. He also introduced an automatic cut-out into the lamp, operated by the ex-

Edison's process for improving platinum for lamp.

Edison's automatic cut-out for platinum incandescent lamps.

pansion of a metal rod that was heated by the incandescing wire when its temperature reached the danger point. Notwithstanding these improvements, it soon became evident to Edison that he must seek some more suitable material than platinum, and we, therefore, soon find him working in carbon.

Edison's paper carbons.

In 1879, Edison made the famous horseshoe carbons of carbonized paper, that created such an intense excitement throughout America and Europe. The belief, which was then general, that the problem of a practical, small electric light was then completely solved, caused a great depression in the value of gas stocks in different parts of the world, the belief being that the new illuminant would entirely displace and render valueless gas lights. As we now know by experience, an improvement in one kind of artificial illumination, so far from driving out pre-existing forms, tends rather to improvements in such forms. This has been the case with electric lighting and gas lighting. Gas lighting today, in the form of the Welsbach mantle, has produced a lamp which, in its sphere of operation, is a formidable rival of incandescent lighting.

How improvements in one form of lighting stimulate improvements in other forms.

The process of manufacture of paper carbons.

Edison first obtained his horseshoe carbon conductors by cutting thin sheets of paper into the form of small horseshoes, and then carbonizing them, that is, subjecting them to the prolonged action of heat while out of contact with air. In this manner, all the volatile portions of the paper were driven out, and the carbon remained in the form of a fragile horseshoe. This, when placed inside a glass globe from which all the air had been removed, and rendered incandescent by the passage of a current, formed what may be regarded as the beginning of the incandescent electric lamp as it exists to-day.

Brief life of paper-carbon lamp.

Edison's bamboo carbons.

The lifetime of this early lamp was exceedingly brief. The paper carbon was rapidly destroyed. Edison, therefore, sought for a better material from which to produce his carbon filaments by the carbonizing process. In 1880, he took out a patent for the use of bamboo fibres for this purpose. In the production of the delicate thread, or filament, as it is generally called to-day, the bamboo was cut into strips, and after the hard external covering, together with the softer interior coating, had been removed, the strips of the fibrous parts were cut into slender rods of uniform thickness, except at the ends, which were left of increased area of cross-section, producing the shape of the bamboo filament shown in Fig. 150. This filament was then carbonized in the usual manner, by prolonged exposure to heat while out of contact with air. The straight filament was then bent into a horseshoe form, and placed inside a glass globe containing a vacuum. Such filaments, when subjected to additional processes, which will be shortly described, produced the commercially successful lamp that was in general use up to a few years ago.

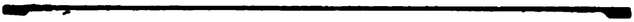


FIG. 150.—The Bamboo Filament. Note the increased area of cross-section of the ends of the filament.

Work of St. George Lane Fox in incandescent lighting.

About the same time, that is, toward the close of 1878, St. George Lane Fox was working in England to produce a practical incandescent electric lamp. At first he employed alloys of platinum and iridium, placed inside a glass globe containing a vacuum. Fox carefully studied the methods for the electrical distribution of the lamps over the space to be lighted, and for the regulation and measurements of the currents employed. Failing to produce practical lamps by metallic wires, he afterward, like other inventors, found a better material in incandescing carbon. Like Sawyer and others, in some of his lamps he surrounded the incandescent conductors by an atmosphere of nitrogen.

As soon as it became evident that a practical carbon incandescent electric lamp could be produced, numerous improvements were made in various parts of the world. Some of these improvements we will shortly describe. Sufficient has been said to show how here, as in all great inventions, the combined efforts of many workers were necessary before the present practical incandescent carbon electric lamp was evolved.

The carbon incandescent lamp the work of many different inventors.

CHAPTER XVIII

PHYSICS OF THE INCANDESCENT LAMP

> "Even the fire-flies' secret, could man once penetrate it, might not prove such a valuable acquisition as it would seem at first thought. To the eye, the light of most species seems greenish, and, in point of fact, it so completely lacks the full red and the violet rays that its effect as an illuminant, on a large scale, would be most disagreeable."—*The Art of Illumination:* Dr. Louis Bell

Distinction between the incandescent and the incandescing electric lamp.

BEFORE discussing the incandescent electric lamp as it is made to-day, it will be necessary to consider some of the more important principles of physics that enter both into its construction and operation. It may be well to call attention here to the fact that we shall use the word incandescent lamp, limiting it to a lamp which is capable of being rendered incandescent by the passage of the current, and the word incandescing lamp, limiting it to a lamp that has actually been rendered incandescent, that is, a lamp that is glowing, or through which the electric current is passing in proper amount.

Efficiency and temperature of filament.

In the first place, it should be remembered that, in the incandescing electric lamp, as in the glowing carbon arc in the arc lamp, the amount of light emitted increases very rapidly with the temperature. Consequently, the quantity of light depends on the temperature of the filament. A high temperature of the incandescing filament is, therefore, requisite to increase the candle-power of the light emitted. It is for this reason that incandescent electric lamps, whose filaments are made of metal spirals, are less efficient than those made of the highly refractory substance carbon, since their temperature is limited by their lower fusing points.

Why the filament of an incandescing lamp should be raised to a high temperature.

But the mere quantity of light, that is, the intensity of illumination, or the candle-power, of an incandescing lamp, is not the only reason for demanding a high temperature of its filament. The daylight-value of the light, or the degree to which the light of the incandescing lamp approaches in its colors to those emitted by ordinary sunlight, is a matter of great importance in any artificial illuminant. When the current of electricity passing through a slender rod of carbon is gradually increased in strength, the carbon at first glows with a dull red light, the rays it emits containing mainly the red colors or rays of the solar spectrum. As the current increases, the glowing carbon emits, along with the red rays, some of the yellow and orange rays, that are found in sunlight. If the temperature of the filament is stopped at this point, although the light emitted by the glowing carbon may suffice for the general purposes of disclosing the outlines or shapes of bodies, yet it would be valueless to disclose the true color values of bodies, which, when illumined by sunlight, emit rays containing, along with other colors, the blue, the indigo and the violet tints of daylight.

An incandescing lamp, whose filament has only received an amount of current capable of producing the red, the yellow, and the orange tints, while capable of giving the true color values of bodies which, when illumined by sunlight, emit colors consisting mainly of mixtures of red, yellow and orange

The color value of light of equal importance with its intensity.

Effect of higher temperature of incandescence.

rays, would be incapable, as above explained, of disclosing the value of bodies containing the other colors of the spectrum. Consequently, unless the filament of an incandescing lamp is heated to the temperature of whiteness, it can not possess true sunlight values. Now this temperature is practically impossible to be maintained, even in the best carbon incandescent lamps. The daylight values of such lamps when in operation can, therefore, never equal those of the arc lamps, which, as we have seen, are raised in the craters of the positive carbons to the highest temperature to which carbon can be heated, *i.e.* to the temperature of its boiling point. Even in the best incandescent electric lamps, the spectrum shows a preponderance of mixtures of the red, yellow and orange rays, and is markedly deficient in the blue and violet rays. Where it is especially desired that the daylight-value of the incandescing lamp shall approach as nearly as possible that of sunlight, it is necessary slightly to increase the E.M.F. to which the lamp terminals are subjected, and thus, by increasing the current strength passing through them, to increase their temperature. Under these circumstances, the lamp will acquire a greater efficiency, that is, will produce a greater amount of light or higher candle-power for the expenditure of a certain amount of energy. But, at the same time, the life of the lamp will be necessarily decreased and lamp renewals must be made more frequently. The advantages, however, under certain circumstances, of obtaining light values more nearly approaching those of daylight may more than compensate for the decrease in the length of the life of the lamp.

Since the character of the light emitted by an incandescing filament depends on its temperature, it is necessary that the temperature of the filament be the same throughout all portions of its length; otherwise, some portions will be at a high temperature, while other portions are scarcely luminous. Such a filament will, necessarily, be extremely inefficient; for, should the temperature of the filament be raised in order to cause the portions of low temperature to emit light, the other portions will become too highly heated, and the life of the filament will, consequently, decrease. Since the temperature of a filament depends on the resistance of its various portions, it is, of course, necessary that it should have throughout its entire length the same area of cross-section. It must, therefore, be made of a substance that can be readily obtained of a uniform electric resistance throughout all portions of its length.

Inefficiency and impracticability of spotty filaments.

In considering the temperature to which a filament can be raised by the passage of an electric current, reference must be had to the opportunities which are afforded for its cooling, and its consequent lowering of temperature. The only means afforded in the modern incandescing electric lamp for the carrying off of its heat by conduction is through the slender leading-in wires, employed for carrying the current into the lamp. These are evidently of too small cross-section to carry off much heat. Moreover, means are always adopted to prevent these wires from acquiring a high temperature, and, in addition, the filament itself is supported on glass, a fairly good non-conductor of heat. If the glass globe were filled with air or other gas, a fairly considerable portion of the heat from the glowing filament would be carried to the walls of the glass globe, and through them to the surrounding air, by means of currents set up in the air within the globe surrounding the glowing filament. When

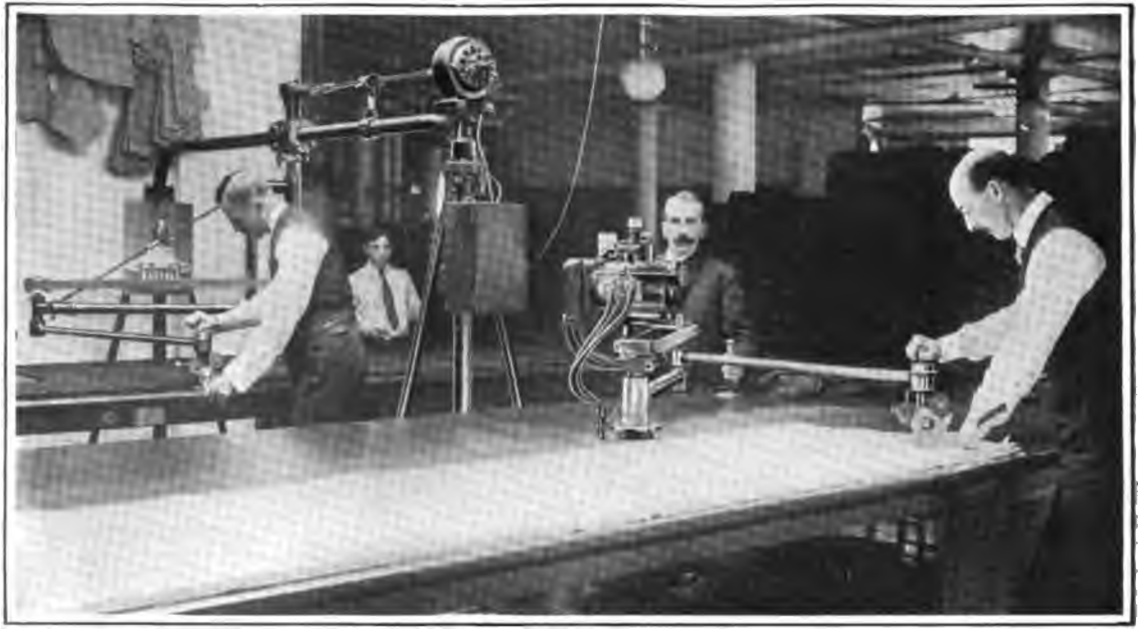
But small quantity of heat of filament lost by conduction.

Heat lost by motion of air in lamp globe.

such air becomes heated by contact with the glowing filament, it is set in motions resembling the winds on the earth, and, by coming in contact with the walls of the globe, carries off the heat in this way. Such a loss of heat must necessarily be attended by a decrease in the quantity of light emitted by the glowing filament.

As we have seen, the most successful incandescing electric lamps are those in which the carbon filaments are placed inside a vacuous space in the globe; and thus the loss of heat of the filament by local winds in the globe is avoided. Where the vacuum in the globe is as high as in the Crookes radiometer, or the residual gas is in the ultra-gaseous state, the number of molecules remaining in the lamp chamber is so small that they are thrown off from the heated surface of the incandescent filament, and do not, as a rule, strike one another, but are thrown from the filament directly to the walls of the inclosing glass chamber, from which they are again thrown in contact with the glowing filament. Every time a molecule touches the filament it carries off a charge of heat. Where, therefore, the vacuum in the globe is not so high, the number of times that the molecules are returned to the surface of the glowing filament by reason of their molecular impact is greatly increased. Consequently, the loss that occurs by reason of the molecular collisions permitting the molecules of the gas to come in contact with the glowing filament, and carry their charges of heat to the walls of the lamp chamber, will be smaller the smaller the vacuum within the globe. Therefore, the loss of heat, and the consequent lowering of temperature from this cause, will be least the higher the vacuum inside the lamp globe.

Loss of heat by molecular impacts.



ELECTRICITY IN THE TAILOR SHOP

Revolving knives driven, through flexible connections, by electric motors. As many as twenty layers of thick cloth can be cut at one time. The operator has only to guide the knife

Radiation the principal way in which the glowing filament loses its heat and lightenergy

It is evident from the above considerations that, in the case of the glowing carbon filament placed inside a lamp globe, in which a high vacuum is maintained, radiation is practically the only way in which the filament can lose or throw off its heat, and with it the accompanying light. A glowing lamp filament, indeed, to be practical, must be able to readily part with its radiant energy, since a portion of this radiant energy is in the form of the light which the lamp is intended to radiate.

Circumstances determining the rate at which the glowing filament radiates its light and heat.

The rate at which a filament loses its heat by radiation depends on its temperature; the higher the temperature the more rapid the radiation. This rate of cooling also depends on the extent of surface of the filament, so that this surface should bear a certain definite proportion to the amount of energy that has been supplied to the filament. In other words, a glowing filament should have a certain radiating surface for the number of watts of energy supplied to it.

The amount of radiation also depends on the character of the surface of the glowing filament. Some surfaces radiate or part with their heat and light much more readily than others. The emissivity of the glowing filament, or the ease with which it can part with its light and heat, will vary according to the condition of its surface. As we shall see, lamp filaments are greatly improved by giving them a character of surface especially favorable for the emission of light from its glowing surface.

Unfortunately for the efficiency of the carbon incandescing electric lamp, the glowing filament emits an exceedingly small proportion of light, or luminous rays, in proportion to the heat, or non-lumi-

Small proportion of light emitted by glowing filament.

nous rays. In a good incandescing lamp, only about 4 parts in every 100 parts of radiation consist of light. The higher the temperature to which the carbon filament can be raised, without too rapid disintegration, the greater the proportion of the luminous to the non-luminous radiation. If, for example, we could safely raise the temperature of a glowing filament to that of the boiling point of carbon, a thing which is clearly impossible, we would obtain a luminous efficiency of the incandescing lamp as high as that in the carbon voltaic arc.

Extremely low luminous efficiency of ordinary luminous sources.

It is an unfortunate fact that all known artificial devices for producing light by means of incandescence obtained through the agency of heat, as in the common candle, gas light, Welsbach light, magnesium light, or arc light, are extremely inefficient. All these devices produce a vastly greater proportion of non-luminous rays of heat than of the desired luminous radiations of light. As we have seen, the incandescing electric light furnishes, as a luminous source, only about 4 per cent of light and 96 per cent of heat. A common candle flame is even lower, yielding only 1½ per cent of light and 98½ per cent of heat; a Welsbach candle yields 2½ per cent of light and 97½ per cent of heat; a magnesium light yields 12 per cent of light and 88 per cent of heat; and, finally, the arc light, which, although the most efficient source of light of this type known, as should necessarily be the case, since here the light is the result of the highest temperature which it is possible to obtain artificially, yet, nevertheless, yields only 13 per cent of light for every 87 per cent of heat.

It would seem, unless some method can be devised for obtaining a more refractory substance than carbon, or some means adopted by which the temperature of the boiling point of carbon can be increased, that we have practically reached the limit of the efficient conversion of heat energy into light energy, unless, indeed, a surface can be discovered highly transparent to light and opaque to heat. That there is a method in which light can be produced in excess of heat is evident, for nature does this constantly in the light emitted by the firefly or the glow-worm. Here the proportion of luminous and non-luminous radiation would, probably, be somewhere in the neighborhood of 98 or 99 per cent of light, and only 2 or 1 per cent of heat. In other words, the radiation of the firefly and the glow-worm produces what might be characterized as cold light, in distinction to the light emitted by the candle flame, the Welsbach, the incandescing electric lamp, the magnesium lamp, and the carbon voltaic arc. There is a peculiar substance secreted in the bodies of these animals that apparently possesses the power of being oxidized by the atmosphere in such a manner as to produce a greater proportion of light rays than heat rays. If it should ever become possible to cheaply produce this substance, it would appear that the problem of cheap artificial illumination would be solved, at least so far as mere light is concerned. Of course, for such a luminous source to be commercially valuable, its light must necessarily possess the same characteristic colored rays as does sunlight. The problem of a satisfactory illuminant, however, will not even then be solved, for, unfortunately, the light of the firefly or the glow-worm does not possess true sunlight values.

High luminous efficiency of the firefly and the glow-worm

Cold light.

Wanted! to discover the secret of the firefly and glow-worm.

The possibility of practically employing the carbon incandescing electric lamp as a source of artificial illumination depends on the fact that, as the

Light emissivity of filament increases with its temperature.

temperature of glowing carbon is increased, its radiating power for light increases more rapidly than does its radiating power for heat, that is, as the temperature of the filament rises above a red heat, its emissivity for light increases more rapidly than does its emissivity for heat. The temperature of the ordinary filament has been estimated at about 2732° F. A slight increase above this temperature materially increases the emissivity of the filament for light; although, as already stated, at a material decrease in the life of the filament. It has been estimated that in a common type of incandescing lamp, an increase of temperature of 40° F. produces an increase of somewhat more than 3 per cent in the candle-power of the lamp.

Short life of early incandescing lamp filaments.

When the carbon incandescing electric lamp first came into use, especially when the glowing filaments were made from the slender, fragile paper carbons, it was possible to maintain them at a fairly bright incandescence but for comparatively short times. Even when the more durable bamboo filaments were employed, although the length of life was materially increased, yet the lamps soon burned out. This difficulty was so great that, at one time, it was feared by some that practical commercial lighting of this character was impracticable. Finally, however, by means of various improvements, lamps are now made which can be economically employed for 1,000 hours without the breaking of the filament.

Necessity for a high vacuum in the lamp globe or bulb.

The means by which this increase of life was obtained was by improvements in the vacuum of the lamp globe. When air is left in the globe the delicate carbon filament is destroyed, either by means of a direct combustion or burning of the filament by its combination with the oxygen of the air, or by the bombardment of the filament by the heated molecules shot off from the walls of the globe or after collisions with one another. This latter effect causes a gradual attrition or wearing of the carbon, sometimes called air washing.

How a small quantity of oxygen may oxidize considerable carbon.

An exceedingly small quantity of oxygen left in the lamp chamber will materially decrease the life of the filament by causing a far greater amount of combustion than would seem possible from the quantity of oxygen actually present. This is believed to be due to the fact that the carbonaceous gases produced by the combustion are subsequently decomposed by the high temperature, depositing solid carbon on the walls of the lamp globe, and liberating oxygen, which can again unite with fresh portions of the filament. In order to avoid this, improvements were made in the methods for obtaining high vacua. But notwithstanding such improvements, the life of the filament still remained low. Lamps in which the vacuum at the start was unquestionably high, soon failed, and on opening the globe after the destruction of the filament, were found to contain a comparatively low vacuum. Careful investigations were made as to the sources of the supposed leakage. Finally, the true cause of the difficulty was discovered, and the lamp globes were exhausted by means of a process that ensured the continuance of the high vacuum, and of the prolonged life of the lamp.

Failure of vacua due to liberation of occluded gases.

As is often the case, the difficulty arose from a fact well known in physics, that had, unfortunately, escaped the notice of inventors; viz., that many substances, especially carbon and platinum, possess the power of occluding gases; *i.e.*, of absorbing and condensing them within their pores. Platinum, for example, can thus absorb several times its volume of hydrogen gas. Carbon also possesses a very high power of thus occluding or absorbing various gases. Gases occluded, or absorbed by solids, are retained with great tenacity, the attraction between the solid and the gas being sufficiently great to actually liquefy the gas. Consequently, when the lamp globe is subjected to the action of the exhaust pump, and the contained air is almost entirely removed, thus leaving a high vacuum in the lamp globe, the occluded gases still remain in a liquid state within the pores of the solids. If, now, the globe is hermetically sealed while in a cold state, as soon as the filament and the different parts of the lamp become heated, the occluded gases are thrown off, and the vacuum seriously vitiated. It was subsequently discovered that a film of highly condensed gas also collected on the surface of the lamp globe and other solids within it.

Simple process for removing the occluded gases.

With the discovery of the cause of the difficulty, the means for removing it were simple. By subjecting the globe and the filament to the action of a high temperature while exhaustion was going on, the occluded gases were driven out of the lamp chamber, the filament, and the conducting wires, and carried out of the chamber by the action of the pump. Various means were adopted to heat the lamp. The method generally employed, however, is to send a somewhat stronger current through the filament than that for which the lamp is made, and then, while the filament and lamp chamber are heated, exhausting and sealing the lamp globes.

The vacuum obtained in the inclosed globe of the incandescing electric lamp of to-day is so excellent that, if the destruction of the filament were only due to its combination with oxygen in its residual atmosphere, or to air washing or molecular bombardments by the residual gas, the life of the filament practically would be almost unlimited. Another source of loss, however, exists, which appears to be due to a kind of evaporation of the filament, both by reason of its high temperature, and of the high vacuum which exists around it. In other words, during the incandescing of the filament, it throws off particles of carbon from its surface somewhat in the same manner that a liquid throws off particles from its surface at temperatures far below those of its boiling point. This gradual wasting not only eventually disintegrates the carbon, but, at the same time, causes a blackening of the inside of the lamp globe, which does more to decrease the life of the lamp than the destruction of the filament itself: for, as we shall shortly see, when an incandescing lamp has reached a certain condition, even though its filament be intact, it is more economical to deliberately break the lamp and replace it by another than to continue its use.

Blackening of the lamp globe by the evaporation of the filament.

There is another reason why the maintenance of the high vacuum in the lamp globe increases the efficiency of the lamp. As we have already seen, low vacua are fairly good conductors of electricity. When, therefore, the vacuum in the lamp globe is a comparatively low vacuum, a peculiar effect sometimes occurs, known generally as the Edison effect, which consists of a pale, bluish light seen around the glowing filament and due to the escape of a part of the current through the conducting low vacuum surrounding it. This loss of current necessarily causes a loss of energy, and decreases the efficiency of the lamp. Since a high vacuum is a non-conductor, this loss almost ceases when the vacuum in the lamp chamber becomes high.

Edison effect.

CHAPTER XIX

MANUFACTURE OF THE ELECTRIC INCANDESCENT LAMP

"How far that little candle throws his beams."
—*The Merchant of Venice,* Act V, Scene I

Enormous growth of the lamp industry.

THE success of the incandescing electric lamp as a source of artificial illumination is evidenced by the great increase in the use of such lamps. This increase is still going on. At the present time it has reached such an extent that one of the principal companies manufacturing incandescent lamps is now turning out some 15,000,000 lamps per year.

United States Census Reports on incandescent electric lamps.

The United States Census Report for 1900 shows that there were some 25,000,000 incandescent lamps manufactured in this country during the census year. Of these, the 16-candle-power lamps reached over 21,000,000. This enormous output, together with improvements in the manufacture of the lamps, has resulted in a lowering of the selling price of single incandescent lamps from the 75 cents or one dollar that was charged for them shortly after their introduction some twenty years ago, to fifteen or eighteen cents, which may be taken as the average charge for each lamp to-day.

Manufacture of the lamp filaments.

In attempting a brief description of the manufacture of the carbon incandescent electric lamp, we will begin with the filaments. These, though of various sizes and shapes, are practically manufactured in the same manner.

Structural and structureless carbon filaments.

As we have seen, the paper carbons were soon replaced by carbonized strips of bamboo or cardboard, or, as they are generally called, of structural carbons. The carbons employed for the incandescing lamp filaments, that are in general use to-day, are squirted carbons, or, as they are sometimes called, structureless carbons, in order to distinguish them from the structural carbons before alluded to.

Squirted carbon filaments.

When ordinary raw cotton is placed in a solution of zinc-chloride, a substance obtained by dissolving zinc in hydrochloric acid, the cotton is dissolved, and a sticky, jelly-like mass is obtained. By forcing this material through a small hole in a plate, and leading the thread which comes out into a vessel filled with alcohol, it soon sets or hardens sufficiently to enable it to be handled. When this thread is carefully washed, and wound on a large drum and dried, it produces a material strongly resembling catgut. The dried thread is then cut into suitable lengths and carbonized while out of contact with air, thus producing carbon filaments.

Advantages of squirted carbons.

The advantages of employing squirted carbons for the filaments of lamps consist not only in the greater uniformity of the resulting carbons, but also in the fact that practically any shape or area of cross-section can be readily obtained. Care must be taken during the squirting process to avoid the presence of minute air bubbles, which would cause a break in the continuity of the filaments, and thus injure them. To this end the solution is filtered while in a hot state in a vacuous space.

Necessity for avoiding bubbles.

Various lengths and areas of cross-sections are given to the filaments of incandescing lamps of different types and sizes. Practically all the different shapes of filaments employed to-day are obtained by suitably bending or looping the straight filaments into the desired form after they have been carbonized. Consequently, when the filaments are removed from the carbonizing oven they are carefully sorted into different classes, according to their lengths and diameters. Such measurements must be made after carbonization, since the filaments shrink considerably during drying and carbonization. Although in the production of the filament every effort is made to obtain carbon threads of absolutely uniform conducting power and area of cross-section throughout all parts of their length, in order that all parts of the filament shall glow or incandesce equally, yet it is found that irregularities will occur. In order to remove such irregularities, an exceedingly ingenious process, called the flashing or treating of the carbons, has been adopted. If an electric current of gradually increasing strength is sent through a filament that possesses any irregularities, either in its composition, or in its area of cross-section, the points of highest resistance will first be rendered incandescent, and afterward the points of next highest resistance. If, therefore, a filament be gradually raised to electric incandescence while surrounded by a hydro-carbon vapor or gas, the points of highest resistance will be first raised to incandescence, and, decomposing the surrounding gas or vapor, deposit a thin coating or layer of electrically conducting carbon on the surfaces of the heated points. This deposit of carbon increases the conducting power of the filament. The next highest points of resistance will then receive a deposit in a similar manner, until, finally, the carbon will glow

Sorting of the carbonized filaments.

The flashing or treatment process for carbon filaments.

Flashed or heated filaments electrically homogeneous throughout all their length.

uniformly at all parts of its surface, thus showing that its electric resistance per unit of length is the same throughout. The flashing process goes on very rapidly, a uniform conducting power being obtained in a few moments.

Some valuable properties of graphitic or deposited carbon.

The carbon deposited on the surface of the filament by the flashing process differs in character from that of which the filament is composed. It may be called graphitic carbon, and has a lower electric resistance than the ordinary carbon. In this respect, the deposited carbon is less favorable for the efficiency of the lamp. It possesses, however, the advantage of having a rather higher emissivity for light than the unheated carbon of the filament does. This deposited carbon also possesses another advantage over ordinary carbon. Ordinary carbon has, approximately, about twice as great an electric resistance when cold as when hot. In other words, the resistance of the filament decreases with an increase in temperature; carbon, in this respect, behaving differently from the ordinary metals. Fortunately, nearly all of this decrease takes place before the carbon begins to glow. This is much better than if the decrease occurred at higher temperatures; for the incandescing lamp is extremely sensitive to small changes in pressure, so that, if most of the decrease in resistance took place at high temperatures, this sensitiveness to small changes of pressure would be much more difficult to avoid. The carbon deposited by the flashing process possesses, however, according to Mr. Howell, the property of increasing in resistance with an increase in temperature.

The deposition of carbon by the flashing process of course decreases the resistance of the carbon, the extent of this decrease depending on the amount of graphitic carbon deposited on the filament. The value of the resistance of the lamp of the various types having been determined upon, the deposition is continued by the flashing process until the resistance of all the filaments of a given type has reached the same value. This can be done either by measuring the resistance of the filament while the deposition is going on, or, the passage of the current through the filament may be automatically stopped by means of an electro-magnet placed in the circuit, as soon as the current strength has reached a predetermined value.

Automatic stoppage of the flashing process.

The next step in the manufacture of the incandescent lamp consists in mounting the filament, that is, in suitably attaching it to a glass support, which is subsequently placed inside the lamp chamber. The leading-in wires or conductors, which carry the current into the lamp, pass through the glass support. Unless care is taken in making a suitable joint at this point, a leakage will occur, which will ruin the high vacuum required.

Joints between the ends of the filament and the ends of the leading-in wires.

The fact that the glowing filament is maintained, as nearly as possible, at a white heat, renders it necessary that the joints between the leading-in wires and the ends of the filament shall be such as will either prevent the joints from attaining a high temperature, or of so making them as will permit them to attain a fairly high temperature without injury. As we have already pointed out, the ends of the carbon filaments are sometimes made of a larger area of cross-section, in order to prevent their becoming too highly heated. The joints between the ends are sometimes obtained by depositing a small mass of copper by electro-plating around the points

Some early forms of joints.

Pasted and deposited joints.

of junction between the filament and the wires. In the early history of the art the wires were sometimes made in the form of a socket, which was tightly squeezed around the ends of the filament. This method, however, has generally been replaced by what is known as the pasted joint, where the ends of the filament and the conductors are pasted together by a mixture of finely powdered carbon and molasses, which is afterward hardened by baking; or, what is a still better method, by means of a deposited joint, in which the ends of the filament and the conductors are joined together by means of

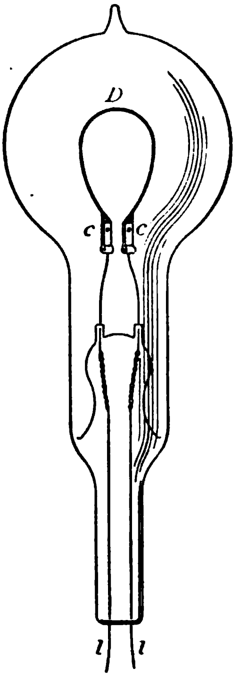


FIG. 151.—Early Form of Lamp Filament Joint. Note the arrangements of the leading-in wires and the early forms of clamps, C, C, for the joints of the filament.

carbon deposited on them by a process similar to the flashing process. An early form of filament joint consisted of small pieces of metal, C, C, Fig. 151, which were suitably clamped to the enlarged ends of the filament D.

Why platinum is used for sealing in glass walls of lamp bulb.

Where the leading-in wires pass through the glass walls of the mount or support, they are fused in the same by melting the glass around them. If these wires were made from such metals as copper, whose rate of expansion differs considerably from that of glass, a slight increase in the temperature of the wires would result in the breaking of the glass, and consequently the destruction of the vacuum. This, however, is readily prevented by making the parts of the leading-in wires that pass through the glass of a metal like platinum, that expands approximately at the same rate that glass does. At the same time, however, care must be taken to prevent the platinum leading-in wires from becoming unduly heated.

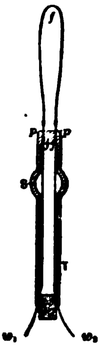


FIG. 152.—Form of Lamp Mount, ready for sealing to lamp bulb.

A form of glass mount for a filament is shown in Fig. 152. Here a small piece of glass tubing, T, has a shoulder blown on it at S. Two platinum wires *p*, *p*, placed inside the tube, are then fused around it by the flame of a blow-pipe. The joint is then carefully annealed.

Cost of platinum wires.

Since platinum is a costly metal, only very short pieces are employed for the leading-in wires, the greater part of the length of such wires being formed of some material like copper, as shown in the above figure at w_1, w_2. Various attempts have been made to employ cheaper metals or metallic alloys to replace the platinum for this purpose. Platinum, however, is still almost universally employed.

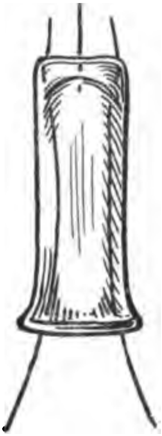


FIG. 153.—Glass Mount for Sawyer-Mann Incandescent Electric Lamp.

Glass mount for Sawyer-Mann lamp

Another form of mount, somewhat similar to the above, is shown in Fig. 153. Here the two short pieces of platinum wire are fused on to the ends of the longer copper wires. The platinum tips are then sealed into the end of a small piece of glass tube, with a short flange formed at one end, as shown at the left-hand side of the figure. A seal is obtained by fusing the glass around the platinum wires, and then compressing and flattening the end of the tube, as shown at the right-hand side of the figure. A short piece of nickel wire is fused into one end of the mount, but does not pass entirely through the glass walls. This wire is intended to serve as an anchor to prevent excessive vibration, and consequent breakage of the glowing filament, as well as to avoid too great a drooping of the carbon when burned in a horizontal position. A filament mounted in this manner is shown in Fig. 154. Here the nickel anchor wire is seen with its upper end connected with the middle of the looped filament. The joints employed in this mount are those of the deposited carbon type, and are of a diameter only comparatively larger than that of either the platinum wires or of the filament itself.

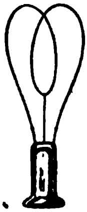


FIG. 154.—Filament Mounted, and ready for sealing into lamp bulb. Note the fact that the nickel anchor wire is fused only to the top of the glass mount, while the leading-in wires to which the ends of the filament are attached pass through the entire length of the glass mount.

Blown and molded lamp globes

Manufacture of lamp bulb.

The mounted filament is now ready to be placed in the lamp globe or bulb. Incandescent lamp bulbs were formerly blown at the end of the glass tube in the air. Now, however, in order always to obtain the same size of bulb, they are blown in suitably shaped molds. The bulb is made in a variety of shapes, according to the purpose for which the lamp is to be employed. The appearance of a common form of bulb as it comes from the mold is shown in Fig. 155. Here, as will be seen, the bulb is closed at the top, and still has attached to it the long glass neck employed in blowing. The next step consists in cutting off this neck by a short file. The cut end is softened in the flame of a blow-pipe, and rounded, and a shoulder formed on it, as shown in Fig. 156. A short glass tube is then sealed to the top of the bulb, and an opening made in the bulb, as seen in the same figure. This tube is provided for the purpose of permitting the lamp bulb to be exhausted when it is suitably connected with the pump.

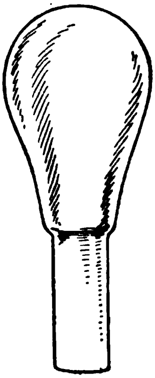


Fig. 155.—First Step in Manufacture of Lamp Bulb. The figure represents the bulb as it comes from the mold. Note the excessive length of the neck.

Fusing together of lamp mount and lamp bulb.

The mounted filament shown in Fig. 154, is now forced up into the lamp bulb, shown in Fig. 156, the elasticity of the filament permitting it to be sufficiently brought together for this purpose. The flange in the neck of the mount is then brought made of a great variety of forms. That shown in Fig. 160 is commonly called the key socket, because it is arranged so that the lamp can be turned on or off by means of the switch or key *k*. Contact pieces are so connected with the supply mains that, when the lamp base is screwed into position in the lamp socket, one of the terminals of the lamp is brought into connection with one of the supply mains, at *a*, and the other lamp terminal with the other supply main, by means of the metallic spring *s*. The metal piece, *b*, is brought into contact with this terminal when the key, *k*, is in the position shown in the fig-

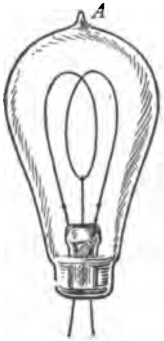


FIG. 158.—Completely Exhausted and Sealed-off Lamp, ready for reception of lamp base. Note the fact that the tube T, of Fig. 157, has been fused off at A, leaving the lamp hermetically sealed at this point.

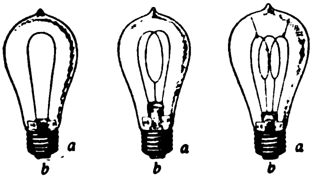


FIG. 159.—Completed Lamps with Lamp Base Attached, ready for being inserted in lamp socket and thus connected with main. Note here three forms of filaments; *i.e.*, the horseshoe, the single loop, and the double loop.

ure. The current is turned off when *k* is moved through a quarter turn, thus breaking the connection between *b* and *s*. In some cases, the lamp socket is not provided with a key attached to the lamp, the lamps being turned on or off by means of a key placed in some position on the wall of the room. Such sockets are called keyless sockets, and are employed for lamps in chandeliers and other similar positions.

Action of key socket.

Keyless lamp sockets.

The exhaustion of the lamp bulbs is first obtained by the use of a mechanical pump, which rapidly carries out the greater part of the contained air. The latter part of the exhaustion is then carried on by some form of mercury pump. The first part of the exhaustion of the lamp bulb is carried on in the cold, until no bubbles of air can be seen passing through the glass pump. This shows that all the air has been removed. An electric current, of somewhat greater strength than is intended to be employed on the lamp, is then sent through the lamp, thus heating it. This is done, as has been already explained, in order to drive off the occluded gases in the filament and leading-in wires, and on the walls of the bulb itself. The pump is kept running until all this

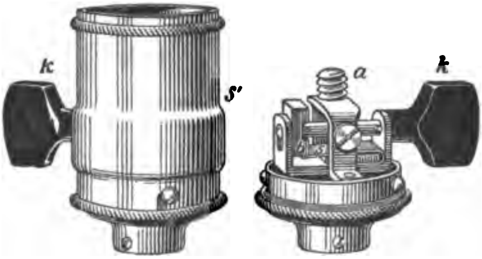


FIG. 160.—Key Socket for Incandescent Electric Lamp. At the left-hand side of the figure the key socket is shown surrounded by a metallic cylinder S'.

Exhaustion of lamp bulb.

Final exhaustion of lamp bulb. gas has been removed, and no bubbles are seen passing through the air pump. The blow-pipe flame is now directed against the small glass tube, T, extending from the top of the bulb, and connecting it with the pump, and the bulb is thus hermetically sealed as already explained.

In order to obtain a higher vacuum than is conveniently possible by the aid of mercury pumps, a process of chemical exhaustion is generally employed; that is, some substance is introduced into the tube which connects the lamp to the blow-pipe, which substance possesses the power of absorbing the small portions of residual gas in the tube. Mechanical pumps are now made that will produce such high vacua that they are sometimes employed in connec-

Chemical exhaustion.

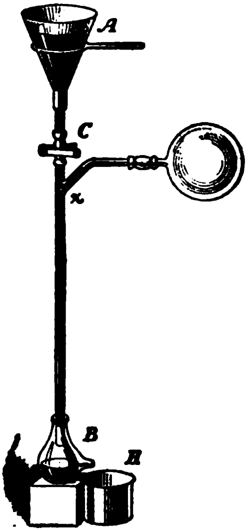


FIG. 161.—Sprengel Mercury Pump. Here G is being emptied or exhausted of its air. In practice, a number of incandescent lamps suitably connected to the pump replace the globe G.

tion with chemical means for the exhaustion of the bulb, without the use of the mercury pump.

A form of mercury pump, very generally employed for exhausting incandescent lamps, is called the Sprengel pump, and is shown in Fig. 161. Here a stream of mercury, falling from the vessel, A, through the vertical tube, exhausts or removes the air from any vessel connected with the upper part of the tube; in this instance, from the glass globe shown as connected with the vertical tube at the point *x*. The falling mercury column, entangling bubbles of air, carries them, mechanically, from the globe down and out at the lower orifice at B. These bubbles are largest at the beginning of the exhaustion, and become smaller and smaller toward the end of the operation. When the bubbles have entirely disappeared, and the sharp metallic click is heard, characteristic of mercury or other liquid falling in a vacuum, the exhaustion may be considered as complete. In order to return the mercury that has fallen through the vertical tube back to the upper reservoir, it is raised again to this level by means of some form of mechanical pump.

Action of Sprengel mercury pump.

CHAPTER XX

THE INCANDESCING ELECTRIC LAMP

> "The next morning the African magician received the twelve lamps. He put them into a basket, which he had provided for the express purpose, and went, with these on his arm, toward Aladdin's palace. When he was near it, he began to cry with a loud voice, 'I will exchange old lamps for new.'"
> —*Arabian Nights*

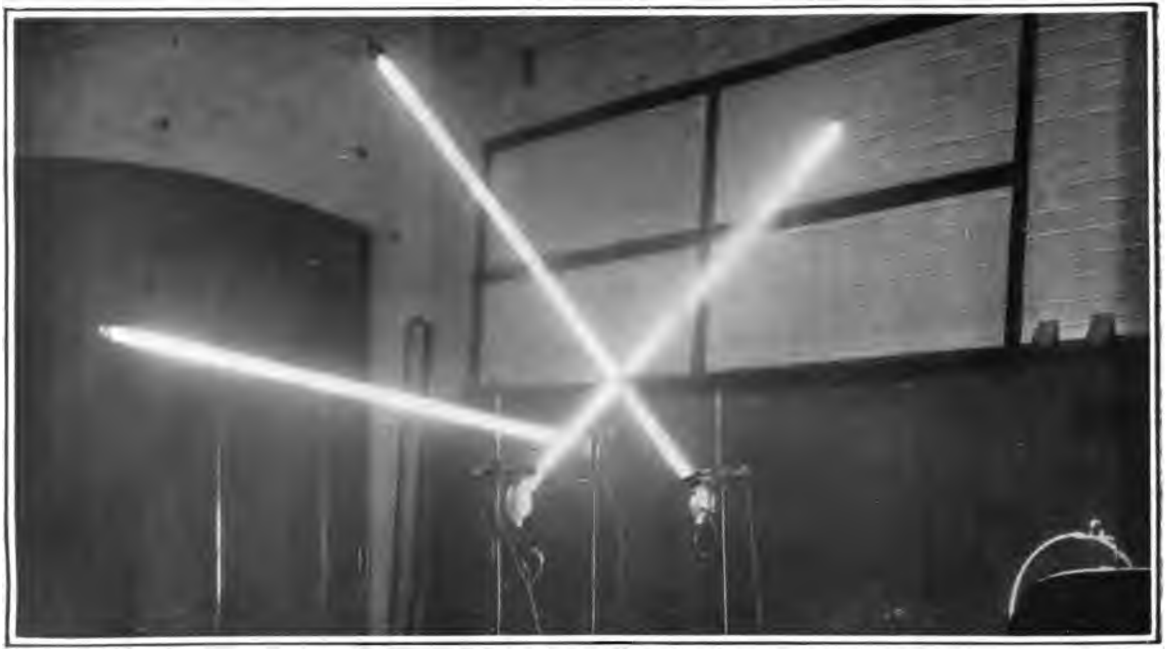
WE will now examine carefully the incandescing electric lamp; *i.e.*, the lamp actually at work in producing light and illumination.

Wastefulness of incandescing lamp.

As we have already explained, the incandescing lamp is an extremely poor device for converting electric energy into light energy, since only about 4 per cent of the energy supplied to the lamp is converted into light energy, the remaining 96 per cent being converted into heat energy.

Brilliancy of lamp.

The brightness or brilliancy of the incandescing filament depends on the temperature to which it is raised. The higher the temperature the greater the surface activity, and, consequently, the greater the brilliancy. The amount of light emitted by the glowing filament, however, depends not only on its surface activity or brilliancy, but also on the length of the filament, or, in other words, on the extent of the surface that is emitting light. Since, in actual practice, the extent of the surface activity of the filament is limited to a particular brightness, the candle-



COOPER HEWITT MERCURY VAPOR LAMP

The three large lamps shown above are photographed by their own light. This form of illumination is very well adapted to purposes of photography, and also, as it is very easy on the eyes, to lighting offices, workshops, draughting rooms, etc.

power of lamps, working under ordinary conditions, will be proportional to the length of the filament. In other words, the total amount of light emitted will depend on the total area of the filament that is emitting light. For example, take the ordinary 16-candle-power incandescing lamp, which requires, approximately, 48 watts of activity for its operation. If 48 watts will produce 16 candle-power of light, we would say that such a lamp is operating at an expenditure of 3 watts per candle. A 32-candle-power lamp, of the same character of filament and the same surface activity, would require twice as much energy to operate it, or would take 96 watts, and, under these circumstances, must necessarily have twice as long a filament, or what is the same thing, twice the surface from which the light is radiated. This doubled surface for emitting the light can generally be most readily obtained by increasing both the length and area of cross-section of the filament. In other words, when a greater candle-power lamp is obtained by the use of the same pressure, and under the same conditions, the filaments are generally larger, that is, longer and thicker.

Total quantity of light.

Relation between candle-power and length and area of cross-section of filament.

The Edison 16-candle-power lamps are made for operation at three different expenditures of energy: viz., at 3.1 watts per candle, where, approximately, twelve 16-candle-power lamps can be obtained by the expenditure of one mechanical horse-power; at 3.5 watts per candle, where, approximately, ten 16-candle-power lamps can be obtained per mechanical horse-power; and at 4 watts per candle, where, approximately, eight 16-candle-power lamps can be obtained from the expenditure of one mechanical horse-power.

Different rates of operating Edison incandescent lamp.

In considering the value of an incandescent lamp, reference must be had, not only to the quantity of light the lamp is capable of producing, or to the number of lamps that can be operated by the expenditure of a single mechanical horse-power, but also to the other extremely important consideration; viz., the extent of useful life of the lamp. We say here useful life, since the lamp may so deteriorate that, without actually breaking, it may consume so much current, and yet produce so little light, that it may be far cheaper to purposely break the lamp and replace it by a new lamp than to continue it in operation.

Useful life of lamp.

As regards the three different rates of operating the lamps above referred to, it has been found by experience that lamps of the highest economy; *i.e.*, 3.1 watts per candle, or twelve 16-candle-power lamps for every mechanical horse-power, can only be satisfactorily employed where the voltage at the lamp terminals is maintained constant. This, as a rule, can only be done where the current is supplied from a central station, where both the appliances installed, and the constant supervision of the plant, ensure the keeping up of a constant pressure on the feeding mains. Lamps of the intermediate economy of 3.5 watts per candle should only be used where the regulation is fairly uniform, and the variation of the pressure on the mains does not exceed 4 per cent; while lamps of the lowest efficiency, or eight 16-candle-power lamps per horse-power, can only be satisfactorily installed on small, isolated plants, where the pressure is apt to vary considerably.

Necessity for maintaining constant pressure at lamp terminals.

Knowing the pressure and the difference of potential of the constant-potential mains, from which the incandescing lamps are to be supplied with cur-

Lengths and diameters of carbon lamp filaments and candle-power.

rent, and having determined the number of watts per candle at which the lamps are to be operated, it only remains to give the filaments, when glowing, the resistance necessary to restrict the electric current to that necessary to produce the required incandescence. This will, of course, depend on the dimensions of the filament, that is, on its length and area of cross-section. If, for example, a given filament operates satisfactorily at a certain number of watts per candle, when placed, say on a 110-volt main, a filament, of the same character, to be suitable for use, under the same conditions, on a 220-volt main, would require to have twice the length, and would then emit twice the candle-power or light, that is, it would produce a 32-candle-power lamp. In point of fact, a 220-volt lamp is sometimes obtained by merely placing two 110-volt filaments in series in the same lamp bulb. If, however, it be desired to produce a 16-candle-power lamp, capable of being operated on a 220-volt main, it would also be necessary to decrease the diameter of the filament. Since such a filament is thinner, and deteriorates much more rapidly than the thicker filament, it is necessary, in order to prolong its life, to operate it

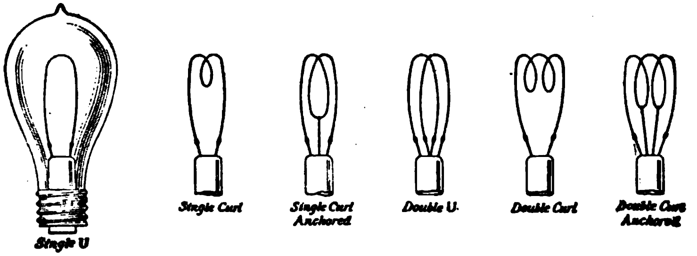


FIG. 162.—Some Different Shapes of Incandescent Lamp Filaments. Note the different expedients adopted to increase the length of the filament. Note also the different methods of anchoring the filament.

at a greater number of watts per candle, or fewer candles to the horse-power.

Lamp filaments are made in a variety of shapes. Some of the principal of these shapes are shown in Fig. 162, taken from Crocker's book on "Electric Lighting." A single U-shaped or horseshoe-shaped filament, which was formerly employed in most of the early forms of lamps, is objectionable, owing to the length of filament sometimes required, together with its tendency to droop when glowing at the high temperatures necessary. Another objection arises from the fact that it requires a larger lamp chamber, and also possesses a poorer distribution of light than other forms of filaments. Consequently, except in low voltage lamps, this form of filament is now almost entirely abandoned, and is replaced by some form of curl filament.

Objections to single U or horseshoe filaments.

The single curl filament, both anchored and unanchored, and the double filament, are very frequently employed for use on constant-potential mains varying from 100 to 125 volts, and for candle-powers varying from 8 to 50 candles. When the length of the filament is considerably increased, the double curl form is employed.

Some differently shaped filaments.

Lamp filaments are anchored in order to prevent them from being broken by vibrations to which the lamps may be exposed, as, for example, on street cars, and also to prevent the glowing filament from sagging or bending when hot and thus coming in contact with the walls of the lamp chamber, which might either break the filament itself, or crack the lamp chamber and ruin the vacuum. The anchors are attached to different parts of the lamp bulb. In some cases, as, for example, in tubular, or, as they

Anchored lamp filaments.

are sometimes called, bung-hole lamps, the anchor is connected to the top of the tube. This would be objectionable in any form of lamp which was intended to throw its light mainly downward, since the anchor wires would produce disagreeable shadows, and thus injure its uniform distribution. There is, however, no objection to this in the tubular lamp, when employed, as is usually the case, for the illumination of shop windows or show-cases, and where, therefore, a side light is desired.

Lamp voltages.

Incandescing lamps are made to operate at various voltages, from a few volts to 220 and upward. When placed on constant-potential mains, the usual voltage for single lamps is generally either 50, 110, or 220 volts.

Low-voltage high-candle power lamps.

For low-voltage lamps, heavier filaments can be employed. This permits the lamps to be operated at 3.1 watts per candle. In such lamps the U-shaped, looped filament is commonly employed. Where high candle-power is required, say up to 100 or 150 candles, heavier filaments are used. These require currents of from 6 to 9 ampères, at 50 volts. In such lamps, the lamp bases must be used in which large contacts are employed. Keyless sockets are to be preferred to key sockets, so that the lamps can be turned on or off at a switch, and not at a socket.

Edison 16-candle-power lamps for 100-volt and 200 to 250-volt mains.

The Edison Company's 16-candle-power, 50-volt lamp is generally operated at 3.1 watts per candle. An Edison Company's 16-c. p. lamp, intended for use on 110-volt mains, is shown on the left-hand side of Fig. 163. Here the filament is U-shaped and is sometimes a single curl, anchored at the middle, the anchor wire being secured to the glass mount. Notwithstanding the increase of voltage in the finer filament, this lamp can operate at 3.1 watts per candle-power, provided the voltage is maintained constant.

High vacuum of high-pressure lamps.

An Edison Company's 16-candle-power lamp, intended to be operated on from 210 to 250-volt mains, is shown at the right-hand side of the above figure. Here the filament is of the double-curl type, anchored at two separate points, as shown. The increased length and delicacy of the filament render it preferable to operate this lamp at 4 watts per candle. The vacuum, as in all such high-pressure lamps, must be extremely high. Consequently, the final exhaustion

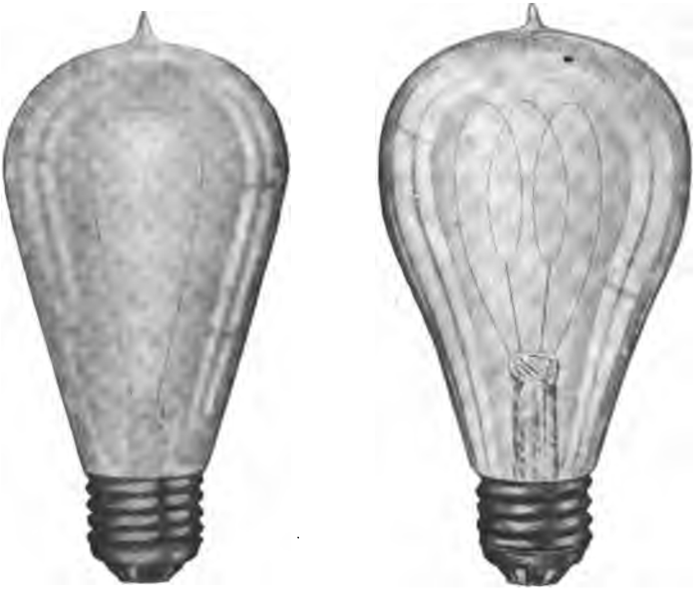


FIG. 163.—**Lamps for Use on 50 and 250 Volt Constant-potential Mains. Note the greater length of its high-pressure filament. It also has a smaller diameter.**

of the lamp bulb is always obtained by the aid of the chemical process.

Tubular lamps for decorating purposes.

Tubular lamps are sometimes employed for decorating purposes, in chandeliers. They are also convenient for the illumination of show-cases, since the shape of the lamp bulb permits it to be concealed inside the show-case underneath the strips of molding. A form of tubular lamp is shown in Fig. 164, of the "Colonial" type.

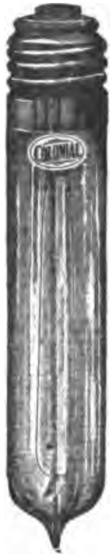


Fig. 164.—Colonial Tubular Incandescent Electric Lamp. This lamp is suitable for side illumination, as for show-cases.

It is sometimes desirable to introduce an electric resistance into a circuit. For this purpose banks of lamps are frequently employed. In such cases a lamp of a special form of filament is employed, a number of separate filaments, connected in series

Lamp filaments of special form of great resistance.

being placed in the same lamp bulb. Such a lamp, with three series-connected filaments, is shown in Fig. 165. Lamps of this type are constructed of a resistance as high as 1,000 ohms when cold, and capable of carrying a current, when hot, of as high as 5 ampères. According to Weber, the temperature of the filament, when operated at 3.1 watts per candle, is somewhere in the neighborhood of 2900° F. When operated at 4 watts per candle, this temperature is approximately 2840° F. These values, however, are only to be regarded as approximate, since the temperatures are only indirectly determined.

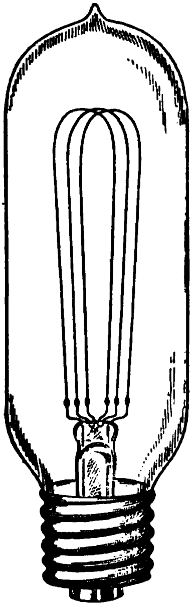


Fig. 165.—Resistance Lamp. Note the manner in which the three filaments are placed in series so that the current passes successively through each.

As we have already seen, the arc lamp emits a

Distribution of light of differently shaped lamp filaments.

Advantages of ground-glass lamp bulbs and reflectors.

much greater amount of light in certain directions than in others. The same is true of the incandescing filament. The distribution of the light of the incandescing lamp varies considerably with the shape of its filament. Generally speaking, the lamp is placed with the tip of the bulb pointing downward. Consequently, in all such cases, lamps are to be preferred which give the greater proportion of their light in this direction. A 16-candle-power incandescing lamp, with a U-shaped filament, will generally give, approximately, 6 candles in the direction of its tip; while a 16-candle-power lamp, with the long-curl, anchored filament, will give as much as 7 candles in this direction; and a 16-candle-power, double-curl filament will give 10 candles in this direction. It must not be forgotten, however, that, for inside lighting, for which incandescent lamps are generally employed, the light which is emitted in nearly every direction from the filament is thrown from the walls, ceiling and articles in the room, on to the different objects to be illumined. Moreover, since, for the lighting of a desk or a book, reflectors or ground-glass bulbs are generally employed, a fairly uniform illumination on the surface of a printed page, or other objects requiring good illumination, will be obtained from nearly any form of filament. It is, however, unquestionably advantageous to employ filaments of such shape that they will naturally throw off the greater proportion of their light in the direction in which such light is to be utilized.

Incandescing lamps of various manufacture vary greatly in the length of time during which they are able to furnish an amount of light equal to that for which they were made. In many cases, lamps that will give either 16 or 32 candles when operated at 3.1 watts per candle, or twelve 16-candle-power

Gradual failure of incandescing electric lamps.

lamps per horse-power, will continue to emit this light only for about 200 hours. By this time the filaments will have become so deteriorated that the lamps only give off 8 or 16 candles respectively. After this point is reached, the lamps have so increased in resistance that, while continued on the mains for which they were desired, it will be almost impossible to supply them with sufficient current to raise the temperature to anything near the point at which the filament could possibly break from high temperatures. Such lamps will continue to burn without breaking for a very long time afterward, and this is a decided disadvantage. Such lamps should be renewed. It is far cheaper to throw away or purposely break them or replace them by new lamps than to continue their use. As we have already stated, there are very few lamps that will continue, when employed 12 to the horse-power, for a longer time than 1,000 hours; and, in point of fact, it is much preferable to place this limit at 600 hours than at the higher limit of 1,000 hours.

Cheaper and better to throw away a depreciated though unbroken lamp than to continue its use.

A plan sometimes adopted to obtain a greater amount of light from deteriorated or aged lamps is to increase the voltage on the mains with which they are connected. This is a mistaken policy, and is especially unfair to the consumer. There is, necessarily, in such cases, an increase in the amount of energy thus furnished to the lamps for which the customer must pay; but with this increase comes a decrease in the amount of light received. The following excellent advice concerning lamp renewals is given by the General Electric Company. Although this advice is given by a company whose business it is to sell lamps, yet it is so manifestly correct that we will quote it, as it furnishes information the general public should possess:

Mistaken policy to increase voltage on aged lamps.

Necessity for frequent lamp renewals.

"The necessity for frequent lamp renewals is urgent on all systems, regardless of the cost of power and whether lamp renewals are charged for or furnished free.

"No matter how well constructed or operated an electric lighting plant may be, it can not furnish clear, good light unless the circuits be periodically swept clean of the dim lamps.

Lamp renewals should not be left to the users of the lamps.

"This cleaning out of dim lamps can not be left to the customer. To be thorough and effective, lamp renewals must be made by the lighting company and without charge. Only by free renewals can a station have that complete control of its lighting service which is requisite to perfect results. The present price of lamps is so low as to make it possible for all stations to furnish free renewals at but slight expense. Free renewals could be profitably adopted by all stations instead of a reduction of rates.

"With free renewals, one of the following methods should be adopted:

Proposed plans for lamp renewals.

"1. Periodically remove all lamps from the circuits one to four times per year, according to conditions, and replace them by new ones. Photometer the lamps removed and save those measuring above a prescribed limit (say 13 candle-power) for use at high voltage points, or locations where reduced candle-power is of slight importance. Scrap the remaining lamps.

The Aladdin method of exchange

"2. Give a new lamp in *exchange* for an *old* one for, say, every $3 worth of current supplied, or for any fixed amount determined by the meter rates and conditions.

"The second plan is an excellent one, in that it offers a bonus for the use of current and regulates renewals on the correct basis of number of hours of lamp service. It can be profitably adopted where-ever meters are in use. A station attendant should visit customers quarterly and instal the number of new lamps due each, removing and returning to the station an equal number of old lamps. . . .

Proposed plans where charges for renewals are made.

"In cases where lamps must be charged for, some measures should be adopted to induce customers to renew their dim lamps: as, otherwise, dim lamps will be continued in service as long as they will burn.

"A good method is to offer new lamps in exchange for dim ones (not burned out) at a reduction in price of one-quarter or one-half cost. A customer, for example, would save by paying, say, half-price for the renewal of a dim lamp, instead of waiting and paying full price when the lamp burns out.

Lamp renewals at less than cost.

"Another method is to offer lamps for renewals at less than cost, say 15 cents each, and reserve the right to say when lamps shall be renewed. Such a plan works well, as no customer can justly complain when the company renews lamps at less than cost.

Quality of lighting service, and not profits on lamp sales, of primary importance.

"The price of lamps to the customer in any case should be made as low as possible—cost price or below cost—for the reason that profit on the sale of lamps is secondary in importance to the sale of current and improvement in quality of lighting service. High charges and illiberal methods in sale or supply of lamps invariably deteriorate the lighting service for the following reasons:

"1. Customers are induced to purchase cheap lamps from outside parties, and therefore use a low grade of lamps.

"2. Customers tend to retain lamps in service as long as they will last, and thus load up the circuits with numbers of old and dim lamps.

"Every station should have some system of lamp renewals, which will not depend upon the customer, and which will limit the average life of the lamps to within 600 hours."

Dimming of lamps by blackening of globes.

There are certain defects that occur during the operation of an incandescing lamp which act to decrease the value of its candle-power. One of these defects arises from the blackening of the lamp globes, due to the deposit of carbon on the inside surfaces. This, of course, decreases the amount of light that can pass through the bulb. Blackening generally results from one of two causes: either the lamp has been subjected to too high a pressure, or it has been kept in operation for too long a time without renewal.

Number of lamps required for sufficient illumination.

For indoor illumination, where 16-candle-power lamps are employed, the number of lamps required for every 100 square feet of floor surface will depend on the general character of the illumination required. This will necessarily vary under different circumstances. An illumination suitable for a church or a library would be insufficient for a ballroom, a hotel dining-room, or a corridor. Generally speaking, however, it may be said that two 16-candle-power lamps for every 100 square feet of floor surface will give what may be regarded as a good illumination; three 16-candle-power lamps per hundred square feet of floor surface will give a very bright illumination; while four 16-candle-power lamps per hundred square feet of such surface will give a brilliant illumination.

The above figures, however, will vary considerably, according to the height of the ceiling, and the color and general character of the surfaces of the walls and ceiling. Dark-colored walls and ceilings absorb light, while the lighter colors throw it off, and aid in ob-

Influence of height of ceilings, and color and character of decoration on number of lamps required.

taining a general uniform illumination by throwing it to different parts of the room. It, therefore, frequently happens, where the ceilings are high, and the general character of the decoration and coloring of the walls and ceilings unfavorable, that the number of lamps above given for every hundred square feet of floor surface will require to be multiplied by 2½ or 3, in order to obtain the proper illumination.

No matter what the character of the illumination may be, care should be taken, whenever the occupation carried on in the illumined room requires the continued use of the eyes, as where a close and constant inspection of the work is necessary, to have not only the work itself properly illumined, but also to ensure a general illumination over all parts of the room, since the change from the amount of light received when the eyes are directed steadily at the work, to that received when they are momentarily directed to the poorly illumined parts of the room, results in a strain that is bad either for good work or good eyesight. In all cases, the eyes should be protected from light directly reaching them from the

Fig. 166.—Artistic Placing of Lamps on Column in Dining-room of Hotel.

Importance of a general illumination in workrooms.

lamp. As a rule, the general use of clear globes or unshaded lamps is objectionable. It is better to employ frosted globes, or to surround the globe by a suitable porcelain shade, especially where the light is intended for use in reading. The effect of employing a frosted globe of ground glass, or other similar material, is to obtain a much more uniform illumination by general diffusion than by the direct falling of the light on the body to be illumined.

Advantages of employment of frosted lamp globe in electrolier.

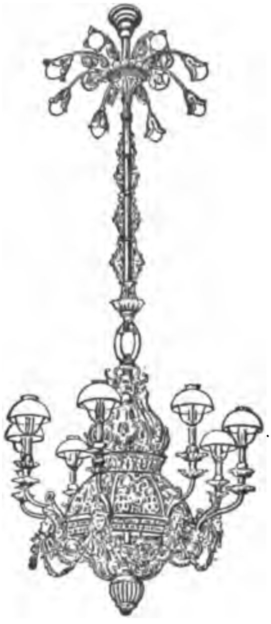


FIG. 167.—Electrolier with Lamps in Pendant and near the Ceiling. This style of distribution is especially suited for rooms with high ceilings.

Various plans are adopted for distributing lamps for inside illumination. Where the room to be illumined is large, or contains a number of high columns or pillars, a very pleasing effect consists in placing a band of lamps in various ornamental designs around the column pillar, at a distance of eight or ten feet above the floor, such, for example, as shown in Fig. 166; or, the lamps may be placed in various forms of chandeliers, or, as they are called when furnished with electric lamps, electroliers, as shown in Fig. 167. Beautiful artistic designs of various types are possible in such a grouping of a number of incandescent lamps. As a rule, when placed in chandeliers, the grouping of the lamps is such that, at times when a very high degree of illumination is not desired, only some of the lamps are lighted, and yet, the general distribution of these few lamps is such that they do not fail to give a pleasing effect from an artistic standpoint. In such cases, keyless sockets are always employed, the different circuits of lamps being controlled by means of switches placed in a suitable position. In cases where chandeliers are employed, additional lamps are generally placed on the walls of the room, on side brackets of various de-

Use of keyless sockets for electroliers and other high-placed lamps.

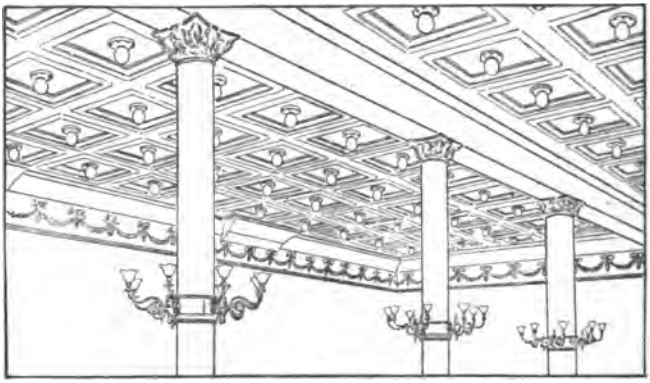


Fig. 168.—Distribution of Electric Lamps in Dining-room of Hotel Marlborough, New York City.

Use of bracket lamps.

signs. Sometimes these two systems are combined with lamps placed in the ceilings, especially when the rooms are high. An example of this combined method of distribution of lamps is shown in Fig.

Electric illumination of Madison Square Tower, New York City.

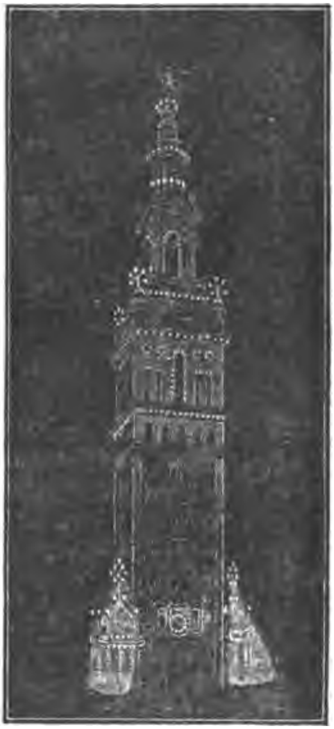


Fig. 169.—Illumination of Madison Square Tower, New York City. When the number of lamps is sufficiently great, this method of outside lighting is very effective.

168. This character of illumination is suitable for halls, dining-rooms, etc.

Incandescent lamps have been very successfully employed for decorative effects required for outside lighting, such as is shown in Fig. 169, where the Madison Square Tower, in New York City, is illumined by incandescent lamps. Very beautiful outside effects are obtained by employing lamps of varying candle-power for the outside illumination of the grounds and buildings in exhibitions, as, for example, shown in Fig. 170, which gives the appearance of the Omaha Exposition grounds when lighted at night.

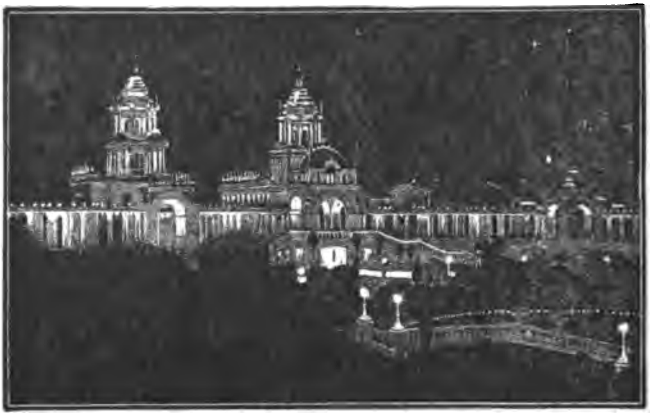


FIG. 170.—Illumination of the Grand Court of the Omaha Exposition.

Illumination of the Omaha Exposition.

CHAPTER XXI

DISTRIBUTION OF INCANDESCENT LAMPS

> "Every room
> Hath blazed with light."
> —*Timon of Athens,* Act I., Scene II

Series and multiple-connected incandescent electric lamps.

INCANDESCENT lamps, like arc lamps, are operated both in series and parallel, and, like arc lamps, may be connected to the terminals of the dynamos or generators that supply them with current, either on constant-current circuits, or on constant-potential circuits. By far the greater number of incandescent lamps, however, are employed in connection with dynamos on constant-potential circuits. In many cases, where the lamps are operated in series, they are placed in groups of series-connected lamps across constant-potential mains. For example, the three series-connected lamps shown in Fig. 171 are placed between constant-potential mains + and —, so that the current from the positive main + enters lamp A, then enters B, and then C, finally returning to the dynamo by the negative main —. In Fig. 172, however, the same + and — mains may have three lamps connected to them in parallel. Here the current branches or divides into three separate paths, passing through the lamps A, B, and C, to the negative main, by which it returns to the dynamo.

Incandescent lamps are sometimes connected directly in series to the terminals of the dynamo. Here constant-current dynamos must be employed. The current supplied by arc-light dynamos has been employed for such purposes. In such cases, the lamp filaments must be made of such short lengths

Incandescent lamps on arc-light circuits.

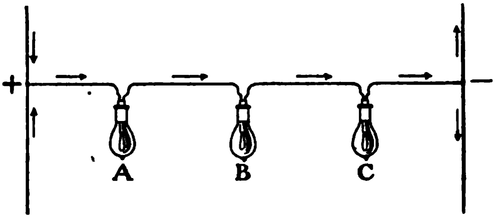


FIG. 171.—Series-connected Incandescent Lamps on Constant-potential Mains. Note here the three series-connected lamps and the passage of the current from the positive main successively through A, B, and C.

and comparatively great areas of cross-section as will enable them to safely take the 9.5 ampères commonly employed on arc-light circuits. As in the case of all series circuits, in order to prevent the failure of any one lamp from extinguishing all the

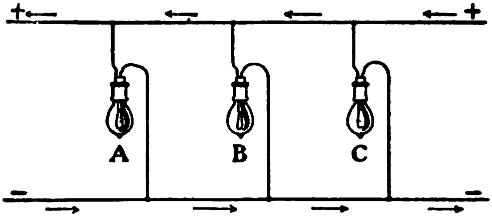


FIG. 172.—Multiple-connected Lamps on Constant-potential Mains. Note here that the current passes simultaneously through the three lamps, A, B, and C, from the positive to the negative main.

remaining lamps on the circuit, some form of safety cut-out must be employed. One of the devices most commonly employed for this purpose is called the film cut-out, in which a thin strip of paper is placed at *f*, Fig. 173, between two metallic strips that are

Film cut-out for series-connected incandescent lamps.

connected to the terminals of the lamp. Ordinarily, therefore, with a pressure of approximately only 6 volts between the lamp terminals that would generally be employed on an arc-light circuit of the type above referred to, this would prevent any of the current from passing at this point. If, however, the filament of the lamp should break, the pressure at its terminals would tend to rise to the full pressure of the machine terminals, which might be as high as a thousand volts. This pressure is sufficient to cause a disruptive spark to pass through the film of paper, where, forming a short arc, it fuses together the two metallic strips and thus completes a permanent path past the faulty lamp.

How the film cut-out short-circuits the faulty lamp.

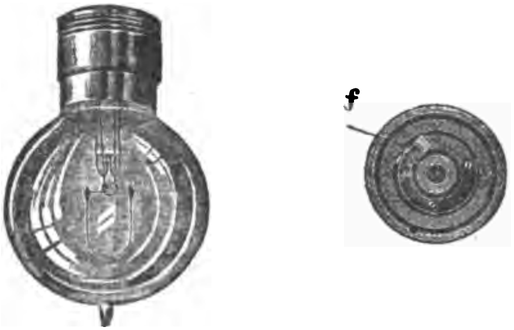


FIG. 173.—Film Cut-out for Series-connected Incandescing Lamps.

Various other methods are sometimes employed for obtaining a series distribution of incandescent lamps for street lighting purposes. Where alternating electric currents are employed, a constant-current transformer is used, of the same type as that employed in the distribution of series alternating-current arc lamps.

Use of constant-current transformer for series distribution of incandescing lamps.

The method is sometimes adopted of placing a number of series-connected lamps across constant-potential mains. Here, however, instead of employing only a few lamps, such as are shown in Fig. 171, the mains are kept at a constant pressure of from 500 to 1,000 volts, by being connected to a single compound-wound, and, consequently, self-regulating generator, D, Fig. 174. A number of series-connected lamps are placed in multiple or parallel on the constant-potential main, as shown in the figure below, where five separate sets of series-connected lamps are placed, so as to be fed from D.

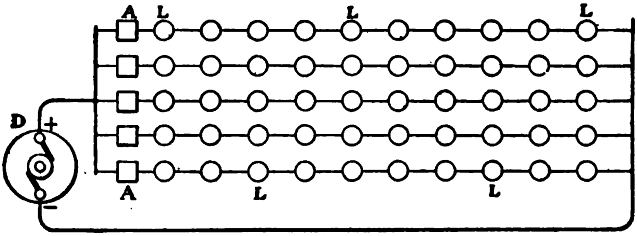


FIG. 174.—Connection of Groups of Series-connected Incandescent Lamps Across Constant-potential Mains. Note that the current indicator, A, is placed at the end of each series-connected circuit of lamps nearer the dynamo D.

Use of current indicator and "relief" or additional lamp in series-connected incandescent lamps.

This method of connection, as we have already seen, is called the parallel-series connection. Wherever it is employed, it is necessary to maintain a constant current in the separate circuits. When, therefore, a lamp filament in any one of the circuits breaks, and is removed from the circuit by the operation of the film cut-out, the current strength in this particular circuit increases. In order to prevent this increase of current from flowing through the remaining lamps and thus injuring them by producing too high a temperature, a current indicator, A, is placed in each separate circuit at the central station. Here an attendant, by looking at the current indicator, will see that one of the lamps has been removed from the particular circuit in which such indicator is placed, and will switch in an additional or "relief" lamp, L, in the circuit, thus restoring the normal current strength.

For inside lighting, incandescent lamps are practically always placed on constant-potential mains. Here, as in Fig. 175, the terminals of the dynamo D are connected with the positive and negative mains respectively, and a number of lamps connected to the mains in parallel. Here four lamps only are shown, for the purpose of simplicity. Let us suppose that the generator is capable of supplying a constant pressure of 112 volts at its terminals, and that in the mains the resistance of the conductors or the leads is such as to cause a loss or drop of potential in the pressure amounting to say two volts. Lamps connected to the ends of such a circuit might, therefore, have a pressure of only say 110 volts, while the lamps nearer to the generator would have a pressure more nearly equal to that existing between its terminals. The drop of pressure on the mains causes all the lamps to receive a pressure somewhat lower than that supplied by the dynamo. Moreover, some of the lamps will receive a pres-

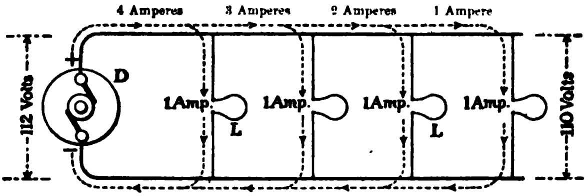


FIG. 175.—Parallel Connection of Incandescent Lamps on Constant-potential Mains.

Necessity for maintenance of constant electric pressure on the mains.

Difference in candle-power caused by a single volt.

sure lower than that received by the others. It is necessary, therefore, that means be taken to prevent too great a drop of pressure on the mains, and too great a difference in the pressure received by the different lamps. In nearly all cases, a comparatively small difference of potential supplied to the lamps will cause a marked difference in the intensity of the light they emit; for example, in most lamps, a difference of a single volt may cause a lamp that would give 16 candle-power at a pressure of 110 volts, to emit only 15 candle-power at 109 volts.

One method of preventing too great a drop of pressure on the mains is by the use of what are called feeders. In a feeder system, wires or conductors, FF, Fig. 176, connect the generator terminals with some distant point of the mains, in this case to the central point of the conductors of the mains A A′ and B B′, and there maintain a certain difference of potential. No lamps are connected with the feeders. Their purpose is solely to maintain a certain pressure at a distant part of a main. For example, in the case shown in Fig. 176, the lamps at the ends A A′ and B B′ of the main may have a pressure of say 114 volts, while those near the central part of such mains may have a somewhat higher pressure, while the pressure at the dynamo may be as great as 145 volts. Usually a number of

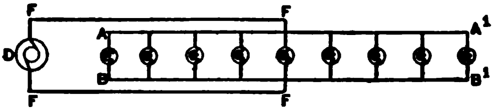


Fig. 176.—System of Feeder Distribution. Here feeders, FF, FF, extend from the dynamo terminals to the central points of the mains A A′ and B B′.

Feeder system for preventing excessive drop of pressure on mains.

A SPEED OF ONE HUNDRED AND TWENTY-FIVE MILES AN HOUR

A car on the Marienfeldt-Zossen Electric Railway, Germany, in full flight. This experimental railroad is being watched with great interest, having already made the fastest time ever accomplished

separate feeders are employed, connected with various parts of long mains.

Greater current capacity required in portions of constant-potential mains near dynamo than in distant portions.

Of course, these differences of potential or drops could be avoided by the use of sufficiently heavy conductors. In the case of the parallel connection of lamps shown in Fig. 175, it is evident that that portion of the mains, near the generator D, must necessarily have a current passing through it sufficient to supply all the lamps that are connected in parallel with the mains. If these lamps take one ampère of current each, then those parts of the mains near the dynamo must convey a current of one ampère to each of the four lamps, or must have a current strength of four ampères passing through it; the next portion will have three ampères; the next two, and the next one, as marked on the figure. In order to save copper, it would not be necessary to have the conducting mains of the same diameter throughout all parts of their length. Therefore, such conductors might be made tapering in form, or conical in shape, thus saving considerable in the weight of the conductor required. Since, however, conical conductors are difficult to produce, the same result may be attained in practice by employing conductors of smaller and smaller areas of cross-section in parts of the circuit, further and further from the generator, through which, consequently, a smaller and a smaller current is required to be passed.

Conductors conical or tapering from dynamo.

Differences in the load, or the number of lamps employed in parallel systems, where feeders are used, such as will occur during different times of the day and night, will necessarily cause a greater drop to take place on the loaded feeders than on the feeders that are comparatively idle. Unless these

Irregularities in pressure caused by variations in load.

differences are provided for, variations will occur in the pressure at the lamp terminals, which will result in annoying irregularities in the amount of light emitted, with a consequent decrease in the life of the lamp. There are various ways in which this difficulty may be avoided; viz., the value of the load on certain comparatively idle feeders may be increased by cutting out some of the feeders from their connection with the bus-bars, the name given to the main terminals that are connected with the dynamos or generators in the central station; or the idle feeders may have an increased resistance introduced into their circuit by the employment of a form of rheostat, called a feeder regulator; or the central station may be provided with generators operating at different pressures.

How load irregularities may be remedied.

Feeder equalizer.

Equalizer switch.

A feeder equalizer consists, as seen in Fig. 177 of a rheostat, containing artificial resistances of iron wires, that are so connected and arranged by the movements of the equalizer switch, shown in Fig. 178, that they may be connected in series or in parallel, and introduced into or removed from the circuit.

Early efforts at high-pressure transmission circuits for multiple-connected incandescent lamps.

The multiple system of distribution of incandescent lamps, or distribution by means of constant-potential mains, requires for the transmission of a given amount of electric energy between the generator or dynamo and some distant point, as we have seen in the case of the arc lamp, a considerably greater weight of copper than its distribution by series-connection to a constant-current system. It has only been for a comparatively few years that incandescent lamps could be successfully operated at greater pressures than from 110 to 120 volts, although, at the present time, as has been pointed out, they can be successfully operated at from 220 to 240 volts. Consequently, early in the history of electric lighting, plans were adopted for decreasing the amount of copper required to transmit the electric energy over circuits of comparatively great lengths. These efforts have always been in the direction of employing pressures higher than 110 or 120 volts, and so placing lamps in connection with mains supplied with such pressures that no more than half the total pressure could possibly be applied at the lamp terminals.

Early plans adopted for decreasing the amount of copper required in long circuits.

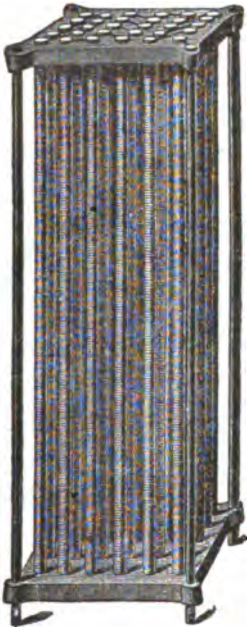


Fig. 177.—Rheostat for Feeder Equalizer. The separate resistances of the vertical spirals of wire are variously grouped or connected by the movements of the equalizer switch represented in Fig. 178.

Perhaps one of the most generally employed of the above systems was invented by Edison in

America, and Hopkins in England, independently of each other. In this system, which was called the three-wire system, instead of employing a single dynamo capable of producing a pressure of 240 volts at its terminals, two separate dynamos were employed, each capable of producing 120 volts at its terminal. These had their positive and negative terminals connected together, as shown in Fig. 179, where the positive terminal of the dynamo D_1 was connected with the negative terminal of the dynamo D_2. In this system, as its name indicates, there are three mains or conductors, AA, BB, and CC. The conductor or main AA, called the positive main, is connected to the positive terminal of D_1; the conductor or main CC, called the negative conductor or main, is connected with the negative terminal of the dynamo D_2; while the conductor or main BB, called the neutral conductor, is connected, as shown, at B, the common junction of D_1 and D_2. The lamps are placed, as shown, between the three mains.

Three-wire system of incandescent lamp distribution

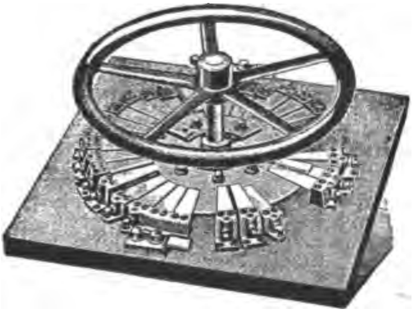


FIG. 178.—Equalizer Switch. The vertical wire spirals of Fig. 177 are connected to the contact points of the switch.

Positive, negative, and neutral mains in three-wire system of distribution

Under these circumstances, there will be a difference of potential between the mains AA and CC of

240 volts, while between AA and BB, or between CC and BB, there will be a difference of potential only one-half as great, or of 120 volts. When all the lamps shown in the figure are in operation, no current whatever flows through the neutral conductor BB. If, however, a greater number of lamps are in use between one set of mains than between the other, then the difference between the current supplied to the two systems of mains will be transmitted through the neutral conductor. When, therefore, as is generally the case, the number of lamps employed on the different mains nearly balance one another, the neutral conductor can be made of much smaller area of cross-section than either the positive or the negative conductor. Consequently, by the use of the three-wire system, a saving can be obtained, in the total weight of the copper required to transmit a given amount of electric energy, amounting, on the average, to about 67 per cent of that required under similar conditions by the two-wire system.

Why the neutral conductor on main may be made of thinner, lighter wire.

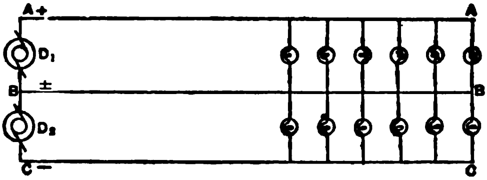


FIG. 179.—Three-wire System of Incandescent Lamp Distribution in Series-multiple.

In actual practice, however, there are many objections to the three-wire system of distribution. In the first place, it requires two separate dynamos; it increases the number of circuits that have to be established and maintained; it increases the number of measuring instruments, switches, and cut-outs

Objections to the three-wire system of lamp distribution.

that are required. Consequently, two-wire circuits are much employed, especially now, since it is possible to employ lamps at pressures of from 220 to 240 volts.

Four, five, and seven-wire systems of distribution.

There have been devised a number of modifications of the three-wire system. Four, five, and even seven-wire systems have also been devised, operating practically on the above principle. Of course, the greater the number of wires the higher the difference of potential employed, and, consequently, the smaller the weight of copper. For example, calling the weight of copper, required for the transmission of a given amount of energy over a given distance by means of the two-wire system, 1,000 lbs., then, on the assumption that the areas of cross-section of all of the wires are equal, the three-wire system, under the same conditions, would take 375 lbs. of copper, the four-wire system 222 lbs. of copper, the five-wire system 156 lbs., and the seven-wire system 97 lbs. The above advantage gained in the weight of the copper required is more than lost by the inconveniences, especially in multi-wire systems above three wires.

Relative weights of conductors required for different systems of lamp distribution.

CHAPTER XXII

SOME SPECIAL TYPES OF INCANDESCENT LAMPS

"Bright as young diamonds."—DRYDEN

INCANDESCENT lamps are made in a great variety of shapes and types, both as regards the shape and character of their filaments, the size, character and shape of the lamp bulbs, the manner in which the lamps are connected to the supply wires or conductors, and the purposes for which the lamps are employed. It will be interesting to examine some of the more important of these forms.

Great variety of incandescing lamps.

Lamps employed in candelabra and electric signs are generally connected in series, in order to simplify the wiring employed. In other words, instead of placing such lamps on the constant-potential mains that are employed for inside wiring in multiple, a number of separate groups of series-connected lamps are placed across such constant-potential mains.

Series-incandescent lamps for constant-potential circuits.

A few of these lamps are shown in Fig. 180. The lamps represented at A, B, D and F are suitable for use in candelabra, and that shown at E for use in illumined signs. The candelabra lamps shown are suitable for connection in series of 2, 3 or 4 across 100 to 120-volt mains, or 2 in series or in multiple across 50 to 60-volt mains. The lamp shown at A is intended to be employed only as a 10-candle-power lamp. The other lamps give a candle-power accord-

Edison series-connected multiple candelabra and sign lamps.

ing to the number that are placed in series in each circuit. For example, on 100 to 120-volt circuits, with 2 lamps in series, each lamp gives 8 candle-power; with 3 in series, each lamp gives 5 candle-power; and with 4 in series, 4 candle-power; while, if burned in multiple on circuits of from 50 to 60 volts, each lamp will give about 8 candle-power. The candelabra shown in Fig. 181 has its lamps series-connected to the mains.

Where smaller candle-power lamps are desired, a greater number of lamps can be placed in series across the mains. For example, the 3-candle-power lamp shown in Fig. 182, is intended to be employed with 8 lamps in series across 110 to 120-volt mains, or with 4 in series across 50 to 60-volt mains. Such lamps require a current of about 1 ampère to maintain them. The 1-candle-power lamp shown in the above figure, is placed 8 in series across 110 to 120-volt mains, or 4 in series across 50 to 60-volt mains. Here each lamp requires a current of about .33 ampères to maintain it. The 3-candle-power lamp is

Some special forms of Edison series lamps

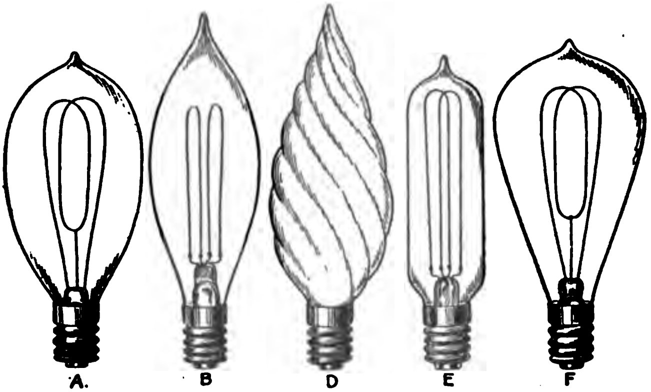


Fig. 180.—Edison Series Candelabra and Sign Lamps.

employed for decorative purposes, where a fairly large quantity of light is desired in each lamp, and where the amount of current that can be obtained is not limited. The comparatively large current traversing the filaments; *i.e.*, 1 ampère, renders it objectionable to employ such lamps for sign work, where the separate lamps are placed near together,

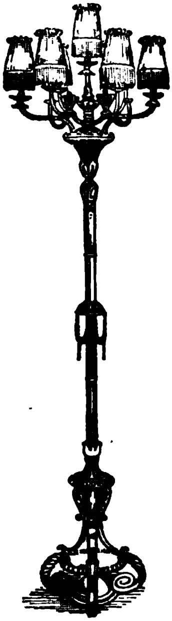


FIG. 181.—Candelabra with Series-connected Lamps in Hotel Parlor.

since the amount of heat they liberate is large. For such purposes, the single-candle-power lamp is preferable. The theatrical lamp, shown in the above figure, gives 1 candle-power when 16 separate lamps are placed in series across 100 to 120-volt mains, or where 8 are placed in series across 50 to 60-volt mains. Such lamps are employed for decorating

The theatrical lamp.

dancers, or for scenic effects. Each lamp requires a current of one-half ampère to maintain it.

Colorless and colored lamp bulbs.

In the employment of incandescing lamps for decoration or for sign work, the lamp bulbs may be made of colorless, clear glass; that is, either transparent or ground. Generally, however, the bulbs are colored, either by dipping them in some suitable liquid, or by making the bulbs of colored glass.

The employment of a number of series-connected incandescing lamps for illuminated signs produces very pleasing and striking effects. Here each letter is represented by a number of separate lamps placed in series, so as to produce the outline of the separate letters. Such a sign is employed by the Delaware & Lackawanna Railroad at one of its piers, as shown in Fig. 183.

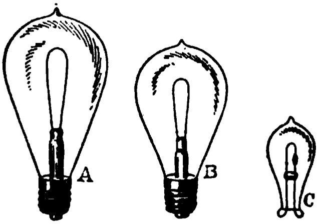


FIG. 182.—Some Special Forms of Edison Series Lamps. The 3-candle-power lamp is represented at A; the 1-candle-power lamp at B, and the theatrical lamp at C.

Socketless series-connected incandescent electric lamps.

Sometimes series-connected lamps of small candle-power are arranged so that no socket is necessary, the lamps being simply looped in series by hooking them together. A lamp of this type, especially intended to be connected 8 in series on 100 to 120-volt mains, and 4 in series on 50 to 60-volt mains, is shown in Fig. 184, where, as is also shown in this figure, a number of such lamps are directly connected together by looping them in series. Such lamps can be employed for the decoration of Christmas trees, but when so employed care should be taken to avoid the formation of minute arcs at the loops by insufficient connection.

For street-car lighting, the lamp filament must necessarily be anchored, so as to prevent breaking from the jolting and vibrations to which the lamps are subjected. But even though anchored, the filaments of such lamps must be made comparatively short and thick, so that both the efficiency and the brilliancy of the illumination are lessened. A lamp suitable for such uses is shown in Fig. 185. Here the filament is anchored by means of a metallic anchor wire, attached to the middle of the loop and the glass mount. This arrangement, by permitting the entire filament to vibrate together, lessens the danger of breakage from excessive vibration. Since

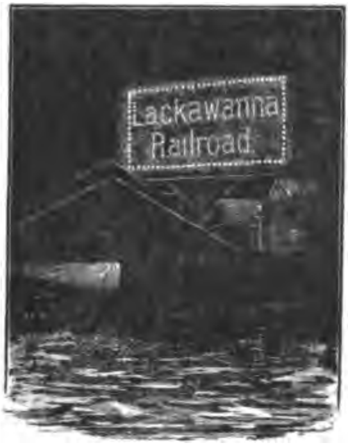


Fig. 183.—Use of Series-connected Incandescent Lamps for Illumined Signs.

Company's standard anchored filament street railway lamp.

railway lamps are operated on circuits whose voltage varies from 550 to 600 volts, they are necessarily placed in such circuit in series. Consequently, their filaments must be so selected as to possess the same current capacity. Street-railway lamps are generally made of from 32 to 16 candle-power, though, of course, they may be made for other candle-powers.

Battery lamps.

The type of lamp known as the battery lamp, is designed for use with either voltaic or storage batteries. Since the voltage produced by such sources is generally small, battery lamps are connected to the source in multiple. Battery lamps are employed for the lighting of steam passenger railway coaches, on which storage batteries are employed. They are made to operate on various voltages with various candle-powers.

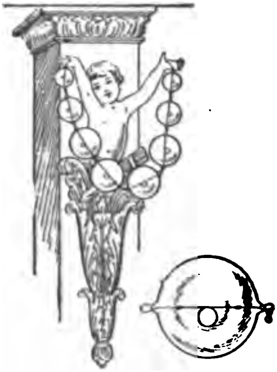


Fig. 184.—Socketless Series-connected Incandescent Electric Lamps. Suitable for use on Christmas trees.

Edison battery lamps.

The Edison battery lamps, shown in Fig. 186, produce the candle-powers that are marked, respectively, under each lamp. Here the one-half candle-power lamp requires an E.M.F. of from 3 to 5 volts, and

Currents and voltages required for small battery lamps.

a current of, approximately, 1 to .6 ampères. The other lamps require the following voltages and currents: viz., 1-candle-power lamp, 4 to 6 volts, 1.4 to .9 ampères; 2-candle-power lamp, 4 to 7 volts, 2 to 1.1 ampères; 3-candle-power lamp, 5 to 7 volts, 2½ to 1.75 ampères; 4-candle-power lamp, 7 to 9 volts, 2½ to 1.75 ampères, and the 6-candle-power lamp, 9 to 12 volts, 2.75 to 2 ampères.

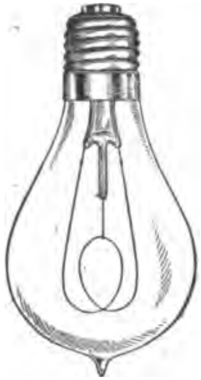


FIG. 185.—Anchored Filament Street Railway Incandescent Lamp. Note the position of the anchor wire and its attachment to the filament.

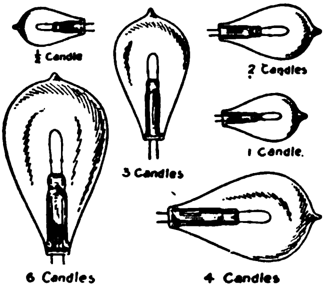


FIG. 186.—Edison Battery Lamps. Note here the relation between the size of the lamp bulb and the value of the candle-power.

Very small battery lamps are employed for the illumination of the mouth. They are made of the form shown in Fig. 187, where the leading-in wires are inserted at the sides of the lamp bulb, as shown,

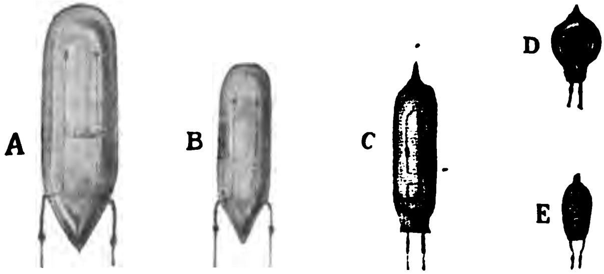


FIG. 187.—Edison Dental and Surgical Incandescent Electric Lamps. The dental side seal lamp is shown at A. B is a special dental side seal lamp. C is a dental lamp with a bottom seal. D is a pea lamp, and E a surgical lamp.

Dental and surgical incandescent lamps.

or sometimes at the bottom. In addition to the dental lamps, the above figure shows two other miniature lamps, called the pea and the surgical lamp.

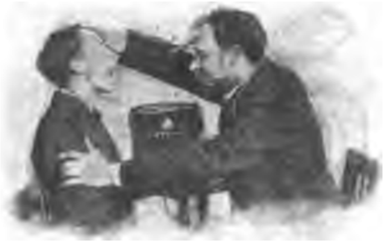


FIG. 187A.—Examining the throat of a patient by means of an incandescent electric lamp fastened to the forehead of the physician.

All the lamps shown in the above figure are of ½ candle-power, and require from 3 to 5 volts, and take a current of from 1 to .6 ampères.

Sometimes small lamps of fairly high candle-power are placed in front of a lens and fastened on the forehead of the physician so as to illumine the throat of a patient that is being examined, as represented in Fig. 187A.

Telephone incandescent electric lamps.

Sometimes, as we shall see in the study of the telephone, small incandescent lamps are placed on the telephone switchboard, for the purpose of acting as visible signals. In order to save space, the lamps are made so that the base occupies a small space on the board. Two forms of telephone lamps are shown in Fig. 188. These are, respectively, ¼ and ½ of a candle-power, and operate, respectively, at pressures varying from 10 to 12, and 20 to 24, volts. They each require a current of .14 ampères.

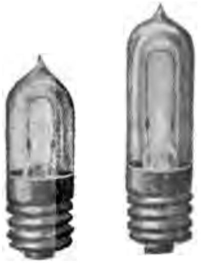


FIG. 188.—Incandescent Lamps for Telephone Switchboards for Visible Signals.

A variety of telephone switchboard with the telephone lamps in place is shown in Fig. 188A. Here the passage of the current displays the signal by lighting the lamp, while the breaking of the current removes the signal by extinguishing the lamp.

Battery lamps for bicycle headlights are sometimes employed, fed either from voltaic or storage bat-

Bicycle and miner's incandescent lamps.

teries. Since, in such cases, the battery power is generally limited, it is necessary to make bicycle lamps of a high economy. That shown in Fig. 189 is capable of yielding about ¾ of a candle-power at 4 volts and .5 ampères. Sometimes, however, lamps are employed which will give .3 of a candle-power at 4 volts and .25 ampères. In the same figure, a 1-candle-power miner's lamp is shown, fed from a small battery carried by the miner. These lamps require from about 3½ to 5½ volts, and from .9 to 1.4 ampères.

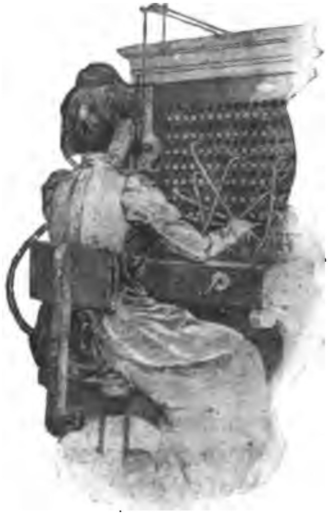


FIG. 188A.—Telephone Switchboard, showing incandescent lamps for visible signals.

A bicycle lamp fed by a storage battery is represented, in Fig. 189A, at work on a bicycle. Sometimes small primary batteries are employed in connection with these lamps.

High candle-power stereopticon incandescent lamp.

Incandescent lamps for lantern or stereopticon apparatus, when made of high candle-power, and designed to be supplied from constant-potential mains, employ heavy filaments, that are concentrated as nearly as possible in a small space, so that the light emitted may come from nearly a single point. For

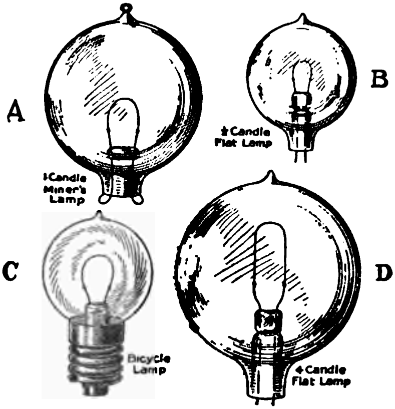


FIG. 189.—Bicycle and Miner's Incandescent Electric Lamps. The 1-candle miner's lamp is shown at A. At B, a 1-2 candle-power lamp with a flat bulb. At C is a bicycle lamp, and at D a 4-candle flat lamp.

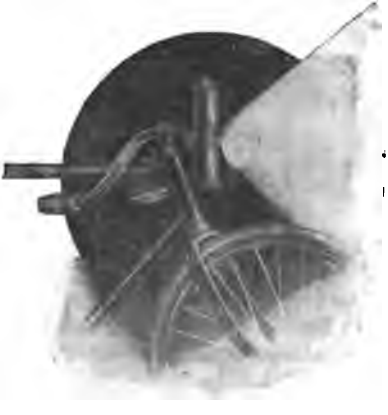


FIG. 189A.—Bicycle Lamp, fed from a storage battery.

this purpose a conical, spirally-shaped filament, such as that shown in Fig. 190, is generally employed. Where a voltaic or a storage battery is to be employed for such lamps, a special form of lamp is required. In such cases, a double looped filament is generally employed.

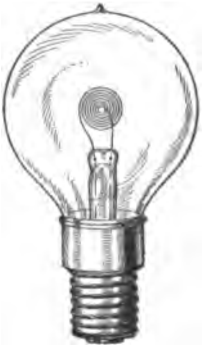


FIG. 190.—Incandescent Lamp, with conical spiral filament for stereopticon. The object of the shape of filament is to concentrate the light in a comparatively small space.

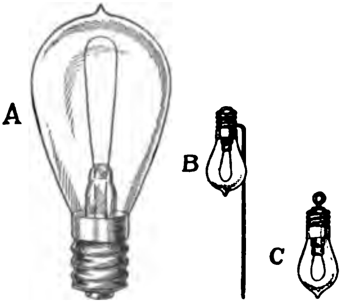


FIG. 191.—Microscope Lamp, incandescent stick-pin, and watch-charm. The microscope lamp is shown at A, the stick-pin at B, and the watch-charm at C.

Microscope lamp, incandescent stick-pins, and watch-charms.

Besides battery lamps of the forms above referred to, there are many others, such, for example, as the small microscopic lamp, shown in Fig. 191, and designed for illuminating an object under microscopic examination. Small, miniature battery lamps are also employed for stick-pins and watch-charms, as shown in the same figure. These lamps are operated by the current from a small storage or primary battery, carried on the body of the person, and operated by a simple push-button, or other switch, concealed in the pocket. The manner of use of the microscope lamp will be readily understood by an examination of Fig. 191 A. A battery lamp, suitable for an automobile, is also shown to the right of Fig. 191 B. It is designed to produce 6 candle-power, at from 22 to 14 volts. The attachment of two such lamps to an automobile is represented to the left of this figure.

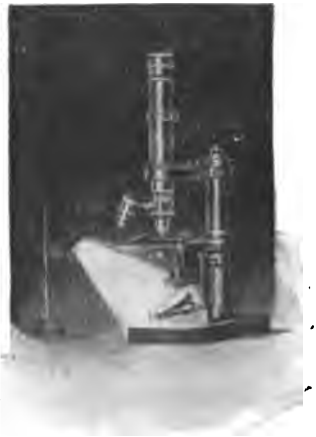


FIG. 191 A.—Microscope Lamp illumining the Reflector of Microscope. Note the fact that the lamp is placed inside a reflector or shade, by means of which it is possible to throw its light on the reflecting mirror of the microscope.

Automobile lamp.

Various devices have been employed for the purpose of turning down an incandescent electric lamp,

Various devices for turning down incandescent electric lamps.

that is, of causing it to emit a smaller quantity of light than usual. Where alternating-current incandescent lamps are employed, this is readily accomplished by the introduction of an inductance or a choking coil into the circuit, since this can be done without any serious loss of energy. An objection to this, however, is in the humming sound accompanying its use. On direct-current circuits, the same thing is accomplished by the introduction of a mere ohmic resistance into the circuit. This, however, is objectionable, on account of the loss of energy so occasioned. On direct-current circuits, therefore, other plans have been devised for turning down the lamp. One of these plans consists in placing two filaments in the same lamp bulb, so arranged that, by the movements of the lamp key, these two filaments can be employed in multiple for full candle-power, or one can be cut out of the circuit for half candle-power, or the two can be connected in series for reduced candle-power. In the Edison night lamp, shown in Fig. 192, the light is turned down by the movements of a small screw, seen at the upper left-hand side of the lamp base.

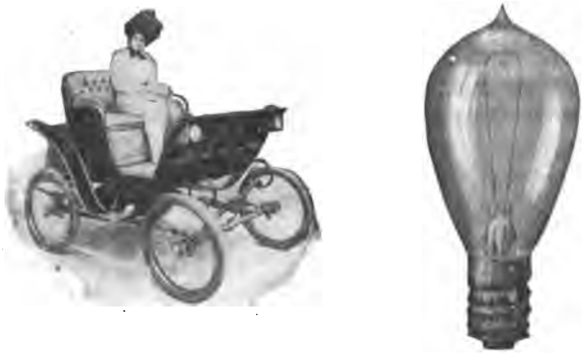


FIG. 191B.—Automobile Lamp and attachment of same to Automobile.

Edison night lamp.

These movements reduce the light by the introduction of resistances in the circuit of the filament.

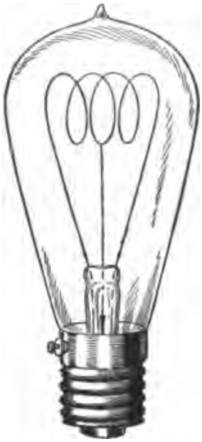


Fig. 192.—Edison Night Lamp.

Twin or double-filament lamp.

Whenever the extinguishment of a lamp might produce serious results, such as where the lamps are

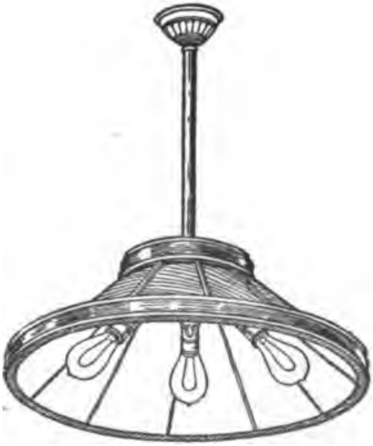


Fig. 193.—Reflector for Group of Incandescent Lamps. Various reflecting substances are employed. Silvered mica is sometimes used.

employed as side-lights for vessels at sea, a lamp called the twin or double-filament lamp is sometimes employed. Here two filaments are placed in parallel across the supply conductor, so that if one lamp is accidentally extinguished, the other will continue burning. Care must be taken not to confound this lamp with the double-filament lamp employed, as described in the preceding paragraph, for the purpose of being able to turn down an electric lamp, so as to vary its intensity.

FIG. 194.—Incandescent Electric Lamp for Desk.

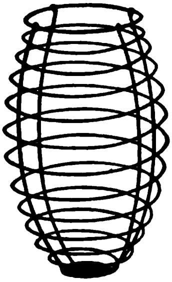


FIG. 195.—Incandescent Lamp Wire Guard.

Where lamps are employed in the open air, and

Water-tight sockets for exposed lamps.

especially at sea, special care must be taken to thoroughly protect the lamp sockets and other exposed parts against the entrance of water. This is readily accomplished by the employment of special water-tight seals.

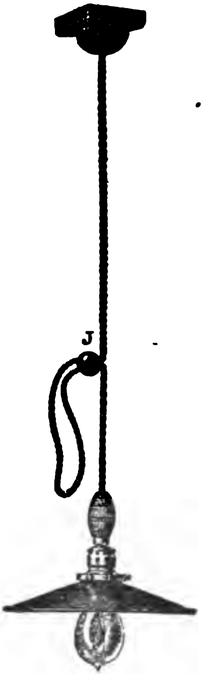


FIG. 196.—Flexible Pendant or Cord for Readily Altering the Height of an Incandescent Lamp. The lamp cord is shortened or lengthened by means of the ball-cord adjuster shown at J.

Various forms of shades and reflectors are employed in connection with the incandescent lamps before described, when employed for general purposes of indoor illumination. These shades or reflectors are placed above the lamps in the usual manner. Several lamps may be placed under a single large shade, as shown in Fig. 193. Sometimes a half metal shade is employed, as shown in Fig. 194. This form of shade is suitable for the illumination of a desk, since the half reflector throws the light downward. Where lamps are placed in positions especially exposed to danger of breakage, they are sometimes protected by surrounding the lamp bulb by a wire guard, as shown in Fig. 195, made in the form of an open wire network. For inside lighting, of course, the use of such shades would be highly objectionable, since the opacity of the wire would prevent the uniform distribution of light needed for illumination.

Half-shade reflectors.

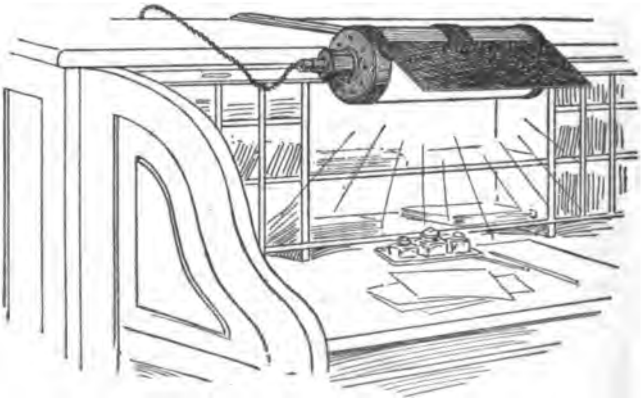
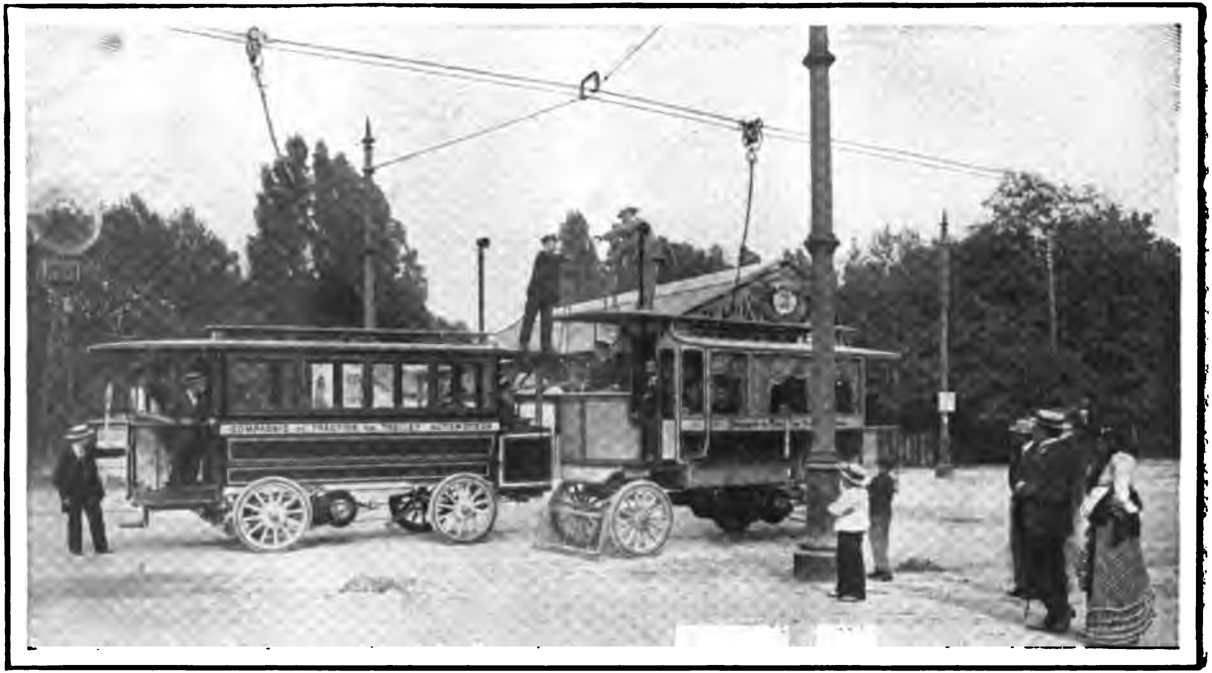


FIG. 197.—Half-shade Reflector, for throwing light in one direction.

Desk lamp.

One advantage which incandescent lighting possesses over ordinary illumination is that, within certain limits, the fixture can be made movable or portable, since the lamp can either be suspended directly from a flexible cord or pendant, as shown in Fig. 196, with a ball-cord adjuster, J, by means of which its height can be readily altered, or the lamp



TRACKLESS TROLLEY IN FRANCE

When the roads are good a trolley line independent of tracks has many advantages. In the illustration, conductors are exchanging trolley connections so that they may pass each other

Ceiling light.

can be connected with such pendant and attached to a flexible support for the purposes of desk lamps, such as shown in Fig. 197. In the lamp shown here the surrounding lamp cylinder is half ground and half clear, and can be turned so that the desk can be illumined either with a clear or a subdued light. Where the lamp is placed in the ceiling of a room, a number of separate lamps are sometimes put inside a single opalescent bowl or half-globe attached to a brass fixture, as shown in Fig. 197A.

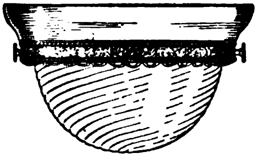


FIG. 197A.—Ceiling Light. Very pleasing effects are produced by placing a number of lamps in a half globe of this character.

Where incandescent electric lamps are suspended from flexible lamp cords or conducting wires, various plans are adopted to readily vary the height of the lamp. In the method shown in Fig. 198 the

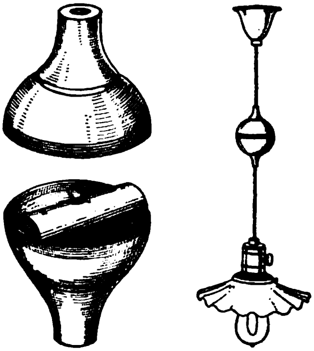


FIG 198.—Lamp Cord Adjuster. The lamp is set at any desired height by raising or lowering it like a curtain.

lamp is raised or lowered by a device similar to the spring in a shade or curtain. The cylinder on which the lamp cord is placed is shown in the enlarged drawing on the left-hand side of the figure.

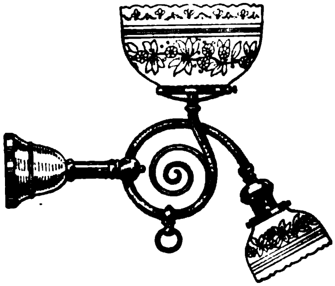


FIG. 199.—Combination Electric Light and Gas Fixture.

Combination gas and electric fixtures.

In cases where rooms are supplied with both gaslight and incandescent lamps, fixtures called combination fixtures, containing both gas jet and incandescent lamps, are employed, as in the form shown in Fig. 199.

CHAPTER XXIII

HOUSE-FIXTURES AND WIRING

> "There can be no doubt that the most important matter to be kept in mind when considering the subject of interior wiring, is the fire risk. This is especially true in this country, where wood enters so much more into the construction of ordinary buildings than it does in European countries."—
> H. Ward Leonard

WHEN incandescent lamps were first introduced, a fear existed that their use would be dangerous to life and would necessarily increase the fire risks. Actual experience, however, has proved that the incandescent electric illumination is far safer than any other artificial illumination. The fact that the source of light is completely covered by a glass globe renders an incandescent lamp far safer as an illuminant than a candle, oil lamp, or gas light. Then, again, the use of the incandescent lamp does away with the use of the dangerous friction match, since the electric lamp merely requires the movement of a key, or of a switch handle, in order to turn on the light. Still again, the use of the incandescent lamp for indoor lighting is more conducive to health. A candle, oil lamp, or gas flame vitiates the air, and renders it unfit for breathing, since these lights require that their combustible materials shall enter into combination with the oxygen of the air. Their long use in a room, where the air is not frequently renewed, renders it unfit for breathing; not only because the life-giving oxygen is removed, but also because such

Incandescent electric lamps safer and more hygienic illuminant than candles, oil lamps, or gas jets.

lights, during their maintenance, throw out into the room a large quantity of useless gas, formed by the union of carbon and oxygen.

Incandescent lamp cooler than candles, lamps, or gas jets.

Although the incandescent lamp bulb becomes heated during use, and so heats the air that comes in contact with it, yet this increase of temperature is far less than that produced by candles, oil lamps, or gas jets, since these illuminants throw off large volumes of heated gases. Consequently, in warm weather, the temperature of a working room becomes much hotter with ordinary illuminants than with incandescent lighting. This fact is especially noticeable in large manufactories, where much night work is done, the operatives being much less fatigued where electric lighting is employed than where any of the old forms of illuminants are used.

Incandescent lighting a safe accident or fire risk.

Accidents arising from the human body receiving dangerous discharges from high-pressure conductors can practically be entirely averted. Indeed, at the present time, both insurance companies and fire departments regard incandescent lighting as possessing far less risks than any other form of illumination. Actual statistics concerning the causes of fires or dangerous accidents show that the number caused by the use of incandescent lighting is far less than that caused by any other system of artificial illumination.

House wires or conductors.

But in order to ensure safety from fires or accidents, great care must be employed in properly installing the wires or conductors that connect the house or building with the street mains. It will be interesting, therefore, to examine somewhat in detail the distribution of the conductors that are employed, in connection with the illumination of a building, from the point where they leave the street mains and enter the house, to the various points at which the lamps are connected.

Where the wires enter the building, in order to prevent the water, during rain storms, from running along the wires, a contrivance called a drip loop is employed. This consists, as shown in Fig. 200, of a drip tube made of porcelain, or other insulating material, through which the conductor passes. This tube slants downward from the opening, so that a fairly sharp bend is given to the wire before it enters the tube. Care must also be taken that the space between the two wires which enter the building should be sufficiently far apart to prevent a short circuit from taking place between them during wet weather. This distance should never be less than twelve inches, and may be preferably even greater than this.

Drip loop.

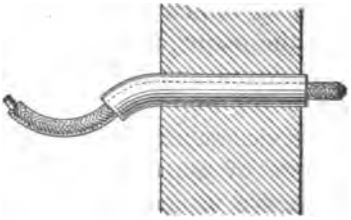


FIG. 200.—Drip Loop, for preventing rain water from entering building along electric wire.

Distance separating neighboring circuit wires.

In order to prevent a current of excessive strength from entering the building, some suitable form of automatic cut-out must be inserted on each of the service wires, as the wires that enter the building are generally called. This cut-out consists of either some form of automatic circuit-breaker, or a fuse

Automatic cut-outs on service wires.

wire, and is so arranged that whenever the current strength exceeds a given value the fuse wire melts and the service wires are thus automatically cut out, or disconnected, from the street mains. The cut-out is placed on the inside wall of the building, as near as possible the point where the service wires enter. From this point the wires extend to the service switch. This switch should contain conductors of such a size that it can safely open the circuit when the maximum current is passing into the house. This switch generally takes the form of a knife switch. Since the handles of such switches, where care is not taken in their construction, will sometimes fall by the action of gravity, arrangements should be made by which this fall will disconnect the house from the mains, rather than connect them with the same.

Service switch.

Beyond the service switches, the conducting wires extend to a piece of apparatus called the switchboard, on which are placed a meter, employed for measuring the amount of current that passes from the street into the building; various switches for the control of the different wires or conductors that pass from the switchboard to different parts of the building, and automatic cut-outs for such wires. In small buildings, conductors pass directly from the switchboard to the different parts of the building, where the various lamps are installed. In large buildings, however, wires called feeder wires may pass to smaller switchboards, called distributing boards or panel boards, from which separate conductors called mains pass in various directions. These mains are furnished with automatic cut-outs, placed in boxes, called cut-out boxes, from which various branch wires pass, to which the lamps, etc., are connected. Sometimes still smaller conductors,

Switchboards.

Distributing or panel boards.

Cut-out boxes.

called taps, are connected to the branch wires. This general character of distribution is shown in Fig.

Branch wires and taps.

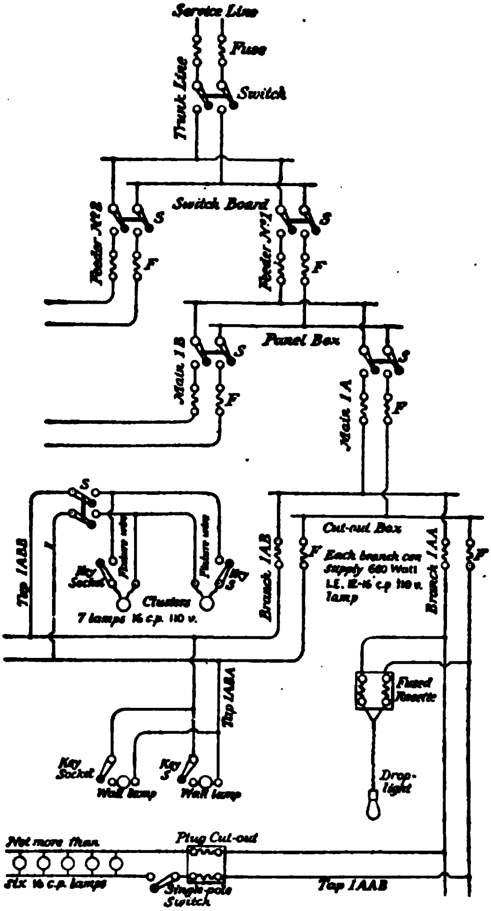


FIG. 201.—Scheme for Interior Wiring of House. Note the connections of the different conductors from the service line, where they enter the building, to the switchboards, feeders, mains, branches, taps, etc.

201, taken from Prof. Crocker's book on "Electric Lighting."

Methods of carrying or supporting inside wires

The wires that extend through various parts of the building may either be concealed, that is, inclosed in a wooden molding, or they may be left open, by being placed on insulated porcelain cleats or knobs; or they may be placed inside various metallic or other tubes, from which they are carefully insulated. The plan formerly adopted of burying wires in the plaster work is objectionable, and should never be employed. The manner of supporting wires on porcelain knobs and cleats is shown in Fig. 202.

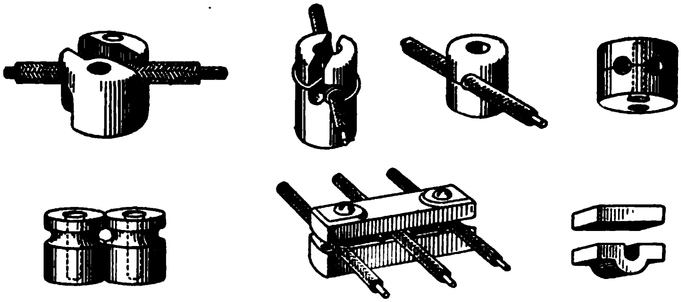


FIG. 202.—Porcelain Knobs and Cleats Employed for Interior Wiring. Note here the different ways in which the wires are clamped or supported.

Safety fuse.

A safety fuse consists of a strip, plate, or bar of lead, or some readily fusible alloy, which safely carries the current up to a certain predetermined strength, but which will instantly become fused, and thus automatically break the circuit, as soon as the current strength passes this limit. As we have already seen, such fuses are employed only in connection with parallel or multiple-connected circuits. The fuses are placed inside boxes lined with some incombustible material, so as to prevent danger from fires being started by the fused metal when the current melts or "blows" on the passage of an excessive current. A form of safety fuse for a large current is shown in Fig. 203, where a strip of fusible metal, F, is placed on a porcelain base between the leads L, L.

Break-down switch.

In some buildings, where isolated plants are employed, and where the electric mains or conductors from a neighboring central station pass through the street on which the building is situated, connection is sometimes made to the street mains, so that, should the dynamo or generator in the building be injured, the electric supply necessary for the operation of its lamps can be immediately obtained from the central station. This is accomplished by means of a switch, called a break-down switch. This switch is of the double-throw type. The connections are such that a movement of the switch handle in one direction connects the conductors of the building with its own dynamo or generator, while its movement in the opposite direction connects them with the street mains. Since, under such circumstances, the central station is obliged to maintain such a possible current output as to be able to supply the building at a moment's notice with a large amount of current, some charge is generally made for this connection, in addition to the charge that would be made for the supply of current that might be occasionally required.

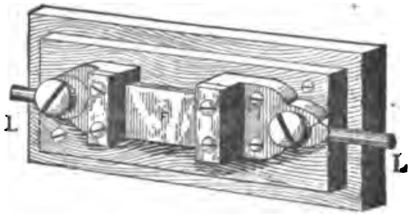


Fig. 203.—Safety Fuse for Large Current.

CHAPTER XXIV

THE COMMERCIAL SALE OF ELECTRICITY

> It is naught, it is naught, saith the buyer; but when he is gone his way, then he boasteth.—*Proverbs* xx. 14

ELECTRICITY, like any other thing of value which has cost money to produce, must be sold at a profit to those who desire to buy it. In order to do this, we must be able fairly to measure the quantity of electricity that passes, so as to know what charge should be made. This is done in a variety of ways, by means of instruments called electric meters, which are not only able to measure the amount of electricity that passes through a given circuit, but are also able to leave a permanent record or registration of this amount. In order to be able correctly to measure so intangible a thing as electricity, we make use of some of the many effects which electricity is able to produce.

Electric meters to measure electricity.

Electric meters are of a variety of forms, and can be divided into classes, according to the character of the effect employed in their operation. For our purposes, however, it is sufficient to divide meters into two classes: viz., those which measure the quantity of current that passes in ampère-hours, and those which measure the amount of energy that passes in watt-hours. An ampère-hour is, in reality, a unit of electric quantity. It is equal to a current of 1 ampère flowing for one hour, and is, therefore, a measure of quantity, 1 ampère-hour being a quan-

Meters that register the ampére-hours and those that register the watt-hours.

tity of electricity equal to 3,600 coulombs. When multiplied by the volts, and expressed in watt-hours, it becomes a measure of energy.

Some requirements for a good electric meter.

It is by no means an easy problem to produce an electric meter which shall be satisfactory alike to buyer and seller. To meet this difficult requirement, the meter must be absolutely fair to both parties, and, moreover, should so record or register its results that such records or registrations can be readily read by either party, so that each can know whether the meters are properly performing their work. Of course, some electric energy must be expended in the operation of a meter, and this should be made as low as possible. Moreover, the introduction of the meter into the consumption circuit should not interfere with the flow of current, or with the pressure on the mains or conductors connected therewith.

Electricity costs more at certain times of the day and year.

After the central station has ascertained, by means of the meters, the quantity either of the electric current or electric energy it has supplied a customer, it remains to determine upon what conditions charges should be made for the same. It would not be fair to the central station, and would, therefore, be unbusinesslike, to charge, at a regular rate, for a certain number of ampère-hours, or watt-hours, unless such charge is based on the fact that it costs the central station more to produce a watt-hour or an ampère-hour at a certain time of the day or year than it does at other times. Unless, therefore, these charges are made so as to cover the average cost per ampère-hour or per watt-hour, an injustice would be done, either to the buyer or to the seller. This arises from the fact that the quantity of energy the central station supplies at different hours of the day, and at different months of the year, varies greatly. In large cities, the load on the central station, that is, the amount of electric energy it is delivering, is especially great generally between 4:30 and 7:30 P.M., during the winter months, and is unusually small during the middle of the day. The central station, however, in order to meet the demand that may be made on it for electric energy, must install sufficient steam boilers, engines, and dynamos to supply the maximum load that may be called for. Consequently, for a large part of the day, much of its apparatus is necessarily idle. It is to the advantage, therefore, of the central station to so arrange with the purchasers of electricity that the load shall, as nearly as possible, be averaged during the twenty-four hours; or, in other words, that an inducement in the way of a smaller charge shall be offered to customers calling for a supply when the load is ordinarily light, and an extra charge for those requiring service when the load is near its maximum.

Maximum load of central station.

Different charge at different hours of the day or night.

Sometimes the central station makes a charge according to the number of lamps installed, whether used or not; or the supply is metered, and a charge made at an average rate; or the supply is metered, and the charge based on the amount of current or energy actually called for. In some cases, however, meters are employed in which a number of separate rates are charged, according to the hour of the day. In such cases, separate meters are employed, which are automatically inserted into or removed from the line at certain hours of the day, by means of a clock. Sometimes a fixed charge is made for all hours, and a certain rebate is allowed for a consumption of energy beyond a given amount. For small consumers a meter is sometimes employed, which is operated by dropping a coin of a certain value in a slot, by means

Basis for charge for supply of electricity.

Slot-meters.

of which the electric current or energy will continue to be supplied until a certain quantity has passed.

Meters that measure the amount of current in ampère-hours are operated in a variety of ways. The form most commonly employed, until within a few years past, was that of the Edison meter, which operated by means of the power which an electric current possesses of decomposing a chemical substance. The Edison chemical meter consists, essentially, of a plating bath, or a glass cell containing a solution of zinc sulphate, in which two plates of chemically pure zinc are dipped. The operation of this meter is based on the fact that when an electric current passes through the solution of zinc sulphate, from one plate to the other, the plate connected with the negative terminal increases in weight, by receiving a deposit of metallic zinc, while the plate connected with the positive terminal decreases in weight, because some of the zinc is dissolved from its surface. The quantity of electric current that has passed is determined by removing the plates from the solution,

Edison chemical meter for measuring ampere-hours.

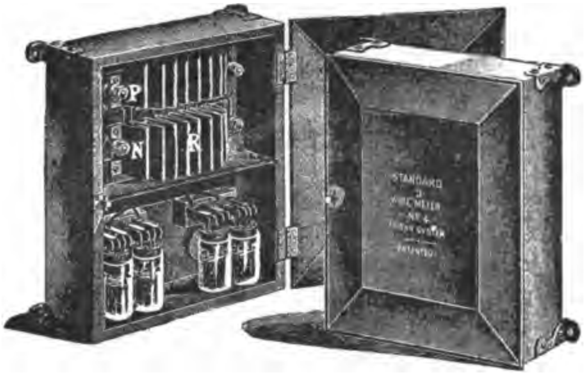


Fig. 204.—Edison Chemical Meter, for measuring electric supply in ampère-hours.

carefully drying and weighing them. An Edison chemical meter of this type is shown in Fig. 204. In this meter only a small proportion of the current passing through the line wires is passed through the solution of zinc sulphate, the meter being placed in a shunt circuit around a resistance, R, of German-silver wire, and another smaller resistance connected in series with the plating bath.

Since the freezing of the solution of zinc sulphate, in cold weather, would interfere with the operation of the meter, Edison adopted the ingenious expedient of introducing an electric lamp inside the meter box, and so arranging its circuit connections that, when the temperature fell below a certain point, the lamp was automatically switched into the circuit, the heat generated by the burning of the lamp being employed to keep the air in the meter box warm. This automatic introduction of the lamp was effected by means of a device called a thermostat. A rod is formed by placing two strips of metal,

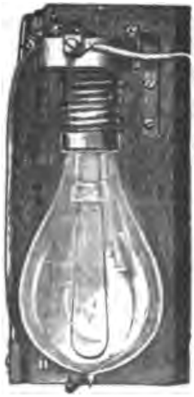


Fig. 205.—Thermo-static Lamp-heater, for preventing freezing of plating bath of Edison's Chemical Meter.

Thermo-static lamp-heater in chemical meter-box.

Action of thermostat.

of different expansibility, parallel one on the other, and riveting them together. Differences of temperature cause this rod to curve in one direction when heated, and in the opposite direction when cooled. When the air inside the meter box falls

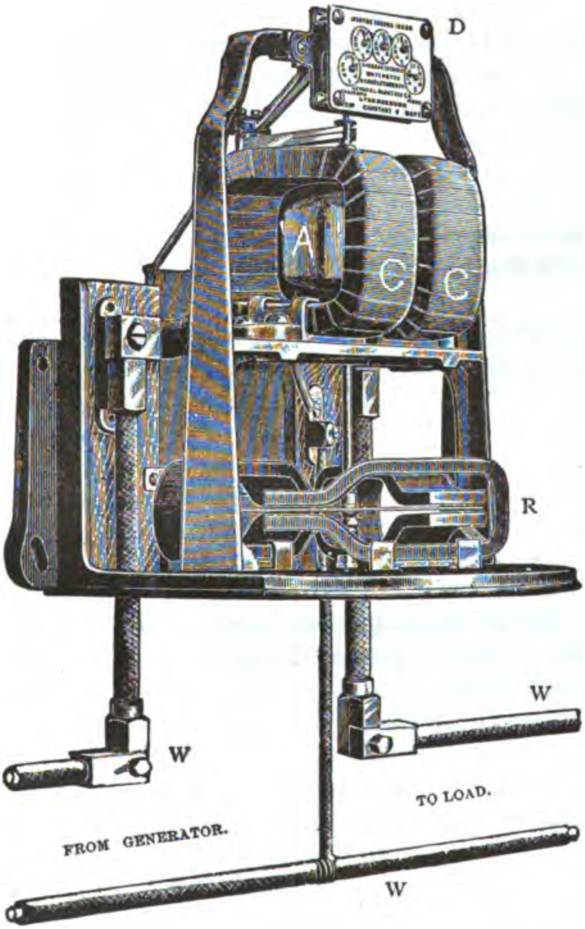


Fig. 206.—Thomson's Electric Two-wire Recording Meter.

below a certain temperature, the movement of the thermostat completes a circuit through a small set-screw, S, shown at the upper left-hand side of Fig. 205, while a movement in the opposite direction, produced by too high a temperature, cuts the lamp out of the circuit. The Edison chemical meter is capable of giving fair measurements of the amount of current passing. By reason, however, of dissatisfaction caused from the inability of customers to read the indications of the meter, it has, in later years, to a great extent, been replaced by registering meters that can be read by the customer.

Why use of Edison meter has been discontinued.

A form of meter for measuring the energy supplied in watt-hours, very generally employed, is that invented by Prof. Elihu Thomson, and shown in Fig. 206. Here the quantity of energy passing is determined by recording the number of revolutions of a small electric motor. This record is effected by means of a mechanism similar to that employed on gas meters, and, therefore, readily understood by the consumer. The field-magnet coils C, C, of this motor are connected in series with the main supply conductors, so that the entire current passes through them. The armature coils, consisting of many turns of fine wire, and, therefore, of high resistance, are placed in a circuit across the mains. The number of revolutions of the armature, or its speed, depends on the quantity of energy passing.

Thomson watt-hour meter.

CHAPTER XXV

THE NERNST LAMP

"On the other hand, an arc between tiny pencils of the material used for Nernst glowers is reputed to give, so far as watts per candle-power go, an efficiency nearly as good as can be claimed for the fire-fly. The experiments in this case are, perhaps, not beyond cavil."—*The Art of Illumination:* Louis Bell

A CURIOUS type of incandescent lamp, which, in some of its earliest forms, required to be started by the heat of a match or the flame of a lamp, but which, when so started, was capable of having its light maintained by the passage of electric current through it, is the Nernst lamp, named after its inventor, Prof. Nernst, of Göttingen.

The Nernst electric lamp.

Unlike the carbon incandescing lamp, the Nernst lamp is not injured when burned in air. Consequently, it does not require to be placed in a vacuum. Indeed, the presence of air appears to be necessary to its proper operation. It is, however, surrounded by a lamp globe, both for the purpose of protecting it from draughts, and preventing too rapid a loss of heat of the glowing part of the lamp and a consequent decrease of its light-giving power. In the Nernst lamp, the carbon filament of the ordinary incandescing lamp is replaced by "a short strip of a material which is an insulator at ordinary temperatures, but which becomes a good conductor and illuminant at higher temperatures." This part of the lamp is called the glower.

Glower of Nernst lamp.

The glower is made of a mixture of several substances, but consists principally either of magnesia or mixtures of refractory oxides, such as those of magnesium, yttrium, zirconium, thorium, and cerium. It is characteristic of these oxides that thev possess a high point of fusion, and can be exposed, while in a highly heated state, to air without any marked deterioration. The glower is rendered incandescent by the passage of an electric current through it, but since these substances are non-conductors at ordinary temperatures, it is necessary to previously raise their temperature before the electric current can pass. This is done, in the non-automatic lamp, by the heat of a match, or an alcohol or gas flame. The glower is about 1-32 of an inch in diameter and about 1 inch in length.

Non-automatic Nernst lamp.

In the automatic Nernst lamp, the preparatory heating of the filaments is done by means of an electric current that passes through coils of wire called the heater coils, composed of two or more small, white, porcelain tubes, of about the thickness of an ordinary lead pencil, and having platinum wire wound around the outside of the tubes. This wire is covered with an insulating refractory paste, which protects the heater coils against the high temperature of the glower. These heater coils are supported or mounted on a block of porcelain, called the heater porcelain. The glower, heater coils and tube, and the heater porcelain, are mounted on a support called the holder. The heaters and glowers are connected to the supply mains in parallel. The holder is provided with contact terminals or conducting prongs, by means of which it is connected to the supply mains.

Heater coils of automatic Nernst lamp.

Nernst lamp-holder

The different parts of the holder of an automatic

Names of parts of Nernst lamp-holder

Nernst lamp are shown in Fig. 207. The glower is here seen as placed above the porcelain heater, coils and tubes, one of which is on each side of the glower. The heater tubes are supported on the heater porcelain, and the contact prongs, for connecting the lamp with the mains, are seen in the lower part of the figure. Since, in the Nernst lamp, a marked decrease in the resistance of the circuit occurs as soon as the temperature of the glower is raised, some plan is necessary for steadying the current by compensating for this change in the resistance. This is effected by means of a device called the ballast or steadying or compensating resistance. It consists of coils of iron wire placed in series with the glower. Since, like most metals, the resistance of iron wire increases with an increase in temperature, as the resistance of the circuit is decreased by the increase in temperature of the glower, it is increased by the increase in the temperature of the ballast wires.

The ballast or steadying resistance of Nernst lamp.

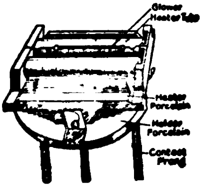


Fig. 207.—Holder of Nernst Lamp. Names of various parts.

Automatic cut-out for heater coils.

In the automatic Nernst lamp, as soon as the current passing through the heater coils has raised the temperature of the glower sufficiently to permit the current to pass through it, an electro-magnet, whose coils are placed in series with the glower, attracts its armature, and removes the heater coils from the circuit. The armature, however, is so arranged that when the glower is taking no current, as at starting, the armature rests in its position on the two contact points, and is so ready for operating when the lamp is started.

Glower and heater coils connected in parallel.

Nernst lamps are intended for operation on constant-potential mains at a pressure of from 200 to 240 volts. The circuit arrangements of the various parts are shown in Fig. 208. Here, as will be seen, the glower and heater coils are connected in parallel with the constant-potential mains. The ballast coils of iron wire are connected in series with the glower and the electro-magnetic coils, whose armature operates the automatic cut-out. The armature of the electro-magnet rests in place on two contact points. The ballast coils of iron wire are placed below the holder.

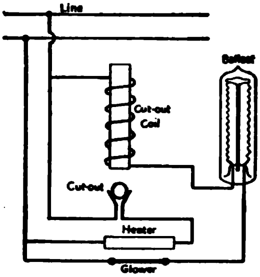


FIG. 208.—Circuit arrangements of Nernst Lamp.

Proper manner to grip the holder in the hand.

The Nernst lamp is made with from 1 to 6 separate glowers. A 6-glower lamp is shown in Fig. 209 which is intended to illustrate the proper manner in which to grip the holder of the lamp in the hand. In this lamp the 6 slender glowers are seen placed near 4 heater tubes. The iron wire ballast is so shown in the part of the lamp below the holder.

A bundle of Nernst heater tubes and glowers is shown in Fig. 210. The heater tubes are seen at the left-hand side of the figure, and the glowers at the right-hand side. It will be noticed that the glowers are of much smaller diameter than the heater tubes. The wires connected with the glowers are intended for connection with the circuit wires. Small aluminium plugs are provided at the ends of the wires connected with the glowers, for attachment to the circuit. The detachable or removable part of the Nernst lamp, as packed for transportation, is shown in Fig. 211. Here one of the covers is removed, showing a 6-glower lamp. The ballast wires are placed below the lamp in the part that is still in the box.

Glowers much smaller than heater tubes.

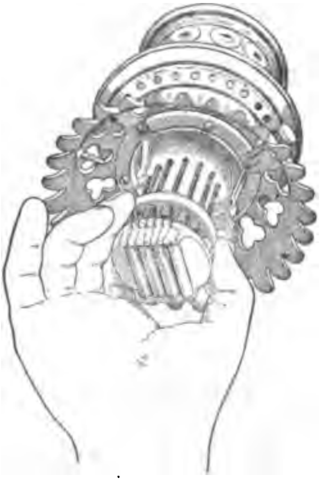


Fig. 209.—Six-glower Nernst Electric Lamp, showing how to grip holder without disturbing the glowers.

Ballast wires.

As to the amount of light the Nernst lamp is capable of emitting, it may be stated that the lamps are designed so that a single glower will produce an amount of light equal to that of a standard 16-candle-power incandescent lamp. Each glower requires about 88 watts, so that the lamps are operated at an economy of about 1.8 watts per candle. This is about half the amount of energy required for the ordinary carbon filament lamp to produce the same quantity of light. At the same time, however, the life of the glower is said to be less than that of the ordinary incandescent lamp. The manufacturers claim that recent improvements have greatly improved the Nernst lamp in this respect. The 2, 3,

Efficiency of Nernst lamps.

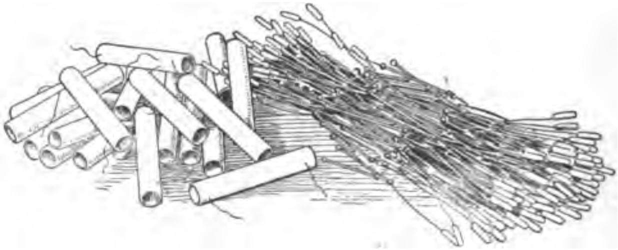


FIG. 210.—Bundle of Heater Tubes and Glowers of Nernst Lamps.

6, etc., glower Nernst lamps require a number of watts which are practically in proportion to the number of glowers, the 2-glower lamp requiring 176 watts, the 3-glower lamp 264 watts, and the 6-glower lamp 528 watts.

Pressures and currents required for different lamps.

Nernst lamps operate equally well on alternating-current circuits at the following voltages: viz., the 6-glower lamp requires 220 volts, and a current of 2.4 ampères; the 3-glower lamp 220 volts, and 1.2 ampères; the 2-glower lamp 220 volts, and .8 ampères; and a 1-glower lamp, for out-of-door work, a pressure of 220 volts and .4 ampères, or a pressure of 110 volts and .8 ampères.

Quality of emitted light.

Since the temperature of the glower can be safely raised higher than the temperature of the incandescing carbon filament, the quality of the light emitted has a daylight value somewhat better than the ordinary incandescent lamp. This feature of the Nernst lamp renders it very favorable for use in stores and other places, such as silk and cotton mills, picture galleries, etc., where a uniform illumination, approaching that of daylight in its character, is required. In order to diffuse the light of the glowers, they are placed inside a globe of clear glass or porcelain. A 1-glower lamp, for out-of-door work, is shown in Fig. 209. A 6-glower lamp is shown in Fig. 212. Here the globe is sufficiently removed from the body of the lamp to expose the glowers, heater coils, and heater porcelain. As many as 30 separate glowers have been employed in single

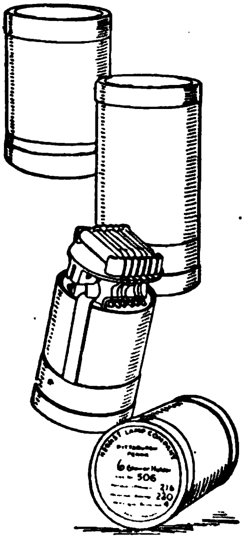


FIG. 211.—Holder Boxes. Lamps packed for transportation.

globes. A Nernst lamp of this general character, with the globe in position for use, is shown in Fig. 213. This form of lamp is suitable for the indoor lighting of large halls. Nernst lamps are also employed for out-of-door lighting. In this case, a suitable cover and reflector are attached to the lamp, the former to protect it from the weather, and the latter to throw the light downward, as shown in Fig. 214.

Nernst lamps suitable for indoor and outdoor lighting.

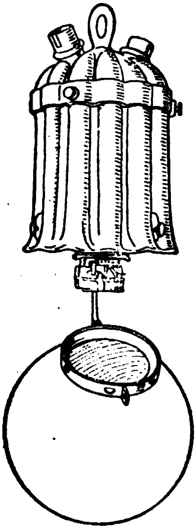
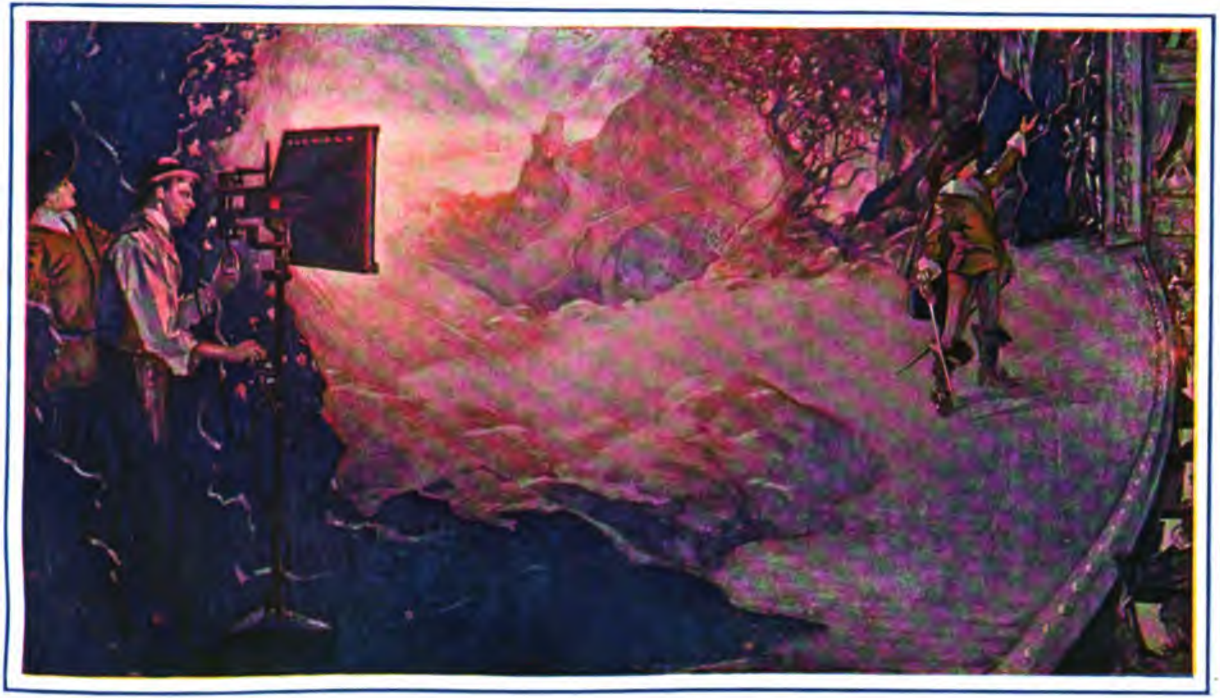


Fig. 212.—Six-glower Out-of-door Nernst Lamp.

Mr. Alexander J. Wurtz, who has done much in America to improve the construction and operation of the Nernst lamp, thus describes, in detail, the connection and method of operation of a six-glower lamp:

"We will examine, in detail, the six-glower lamp as typical of all the others. This lamp is suspended from an eye-bolt, which, being removed, allows of immediate access to the inner parts. On removing



THE USE OF ELECTRICITY ON THE STAGE

the housing, we find that the ballasts are placed in a semicircle around the cut-out, the arrangements of the parts being such as to make all easy of access. The connections are made with small aluminium

Wurtz's description of six-glower Nernst lamp.

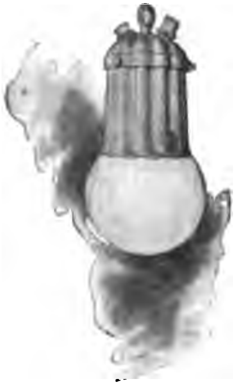


FIG. 213.—Six-glower Out-door Type of Nernst Lamp.

plugs on the ends of the interconnecting wires, which avoid the many familiar inconveniences associated with set-screws. All the parts are mounted on porcelain; in fact, there is no combustible material whatever in the lamp. The heaters and glowers are attached to a removable piece or 'holder,' the design being such that the heaters, backed by a porcelain disk, are immediately above the glowers, resulting in the following advantages: Stagnation

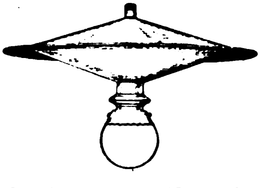


FIG. 214.—One-glower Out-door Type of Nernst Lamp for street lighting.

of heat from the heater, thereby lighting the glowers in minimum time; no shadows, nearly all the light being thrown downward, where it is ordinarily most desired; stagnation of heat from the glowers, whereby the latter are run in their own heat, and, therefore, at a higher efficiency than they would otherwise. The glowers and heaters are attached to

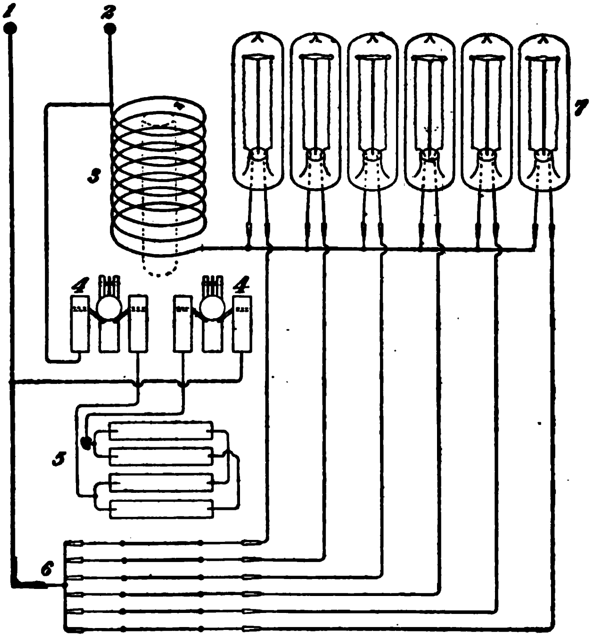


FIG. 215.—Circuit Connections of Six-glower Nernst Lamp. Here the six separate glowers are represented as placed together, merely for convenience.

Use of aluminium plugs for attachment of glowers.

the binding posts of the holder by means of small aluminium plugs, so that the perishable members are always easily and conveniently interchangeable. The holder is provided with nine contact prongs, which, when the holder is pushed up into the lamp, automatically make the desired connections. These are shown in Fig. 7 [our Fig. 215]; 1 and 2 represent the line terminals; 3 the actuating coil; 4 and 4 the double-pole cut-out; 5 the heater; 6 the glowers; and 7 the ballasts, there being, of course, one ballast for each glower. A small glass globe, called the 'heater-case,' is held by spring clamps around the glowers, the function of which is to retain the heat and thereby decrease the time of lighting as well as increase the efficiency of the glowers. In service, the 'heater porcelain,' which is the porcelain disk immediately above the heater, becomes coated with a thin layer of platinum black, unless measures are taken to prevent it; and this not only decreases the illuminating power of the lamp, but if not removed, will in course of time become conducting and cause leakage of current. No simple means have been discovered for removing the platinum black from the porcelain surface. This difficulty, nevertheless, has been avoided by coating the surface of the porcelain with a thin layer of white paste, which may be easily removed with a stiff brush or scraper. The platinum black now deposits on this coating, both of which may be removed together, leaving the fresh, white surface of the original porcelain to be recoated for further service; but even should the platinum black be allowed to accumulate, all danger of leakage currents is avoided by surrounding the holes through which the lead wires pass, by small, annular rings or grooves, it having been discovered that the platinum black will not deposit in these small spaces; the continuity of the platinum black surface between the lead wires is thereby interrupted. For higher candle-powers, the six-glower holder is used as a unit, and this may be multiplied to any desired limit.

Heater-case.

Heater porcelain

How the platinum black may be removed

"The quality of the light is remarkable for its beauty and close approximation to daylight. All colors are seen in their proper shade, making the light especially desirable in stores, art galleries, drawing-rooms, and the like. The absence of shadow, the steadiness of the light, the simplicity and low cost of maintenance, the high efficiency of the lamp, and the fact that it is operative on 3,000 alternations, are features that will commend themselves strongly to the lighting world."

Quality of light.

CHAPTER XXVI

THE COOPER HEWITT MERCURY VAPOR LAMP

"When Dr. Cooper Hewitt undertook to develop a new source of illumination, which should be at once easily capable of practical application, and more economical in operation than the methods then in use, he selected one of the most difficult of the prominent physical problems which for a long time have been crying for solution."—DR. A. P. WILLIS in *The Electrical Age*, February, 1904.

Cooper Hewitt vapor lamp.

ATTENTION has already been called to the fact that in 1856 an Englishman named Way produced a variety of arc lamp in which a form of flowing mercury electrode was employed. Recently a variety of vacuum-tube lamp has been invented by Peter Cooper Hewitt, of New York City, in which the vacuous space is filled with vapor of mercury. The passage of an electric current through the enclosed mercury vapor raises it to incandescence with the emission of a comparatively intense light.

Interesting features of lamp.

A high efficiency is claimed for the Cooper Hewitt mercury vapor lamp. Like all other vacuum-tube lamps, it emits a light that is uniformly diffused, owing to the extended surface from which the light emanates. In experimenting with various gaseous substances, Hewitt found mercury vapor to give out the greatest amount of light. Unfortunately, however, the light of incandescent mercury vapor is deficient in the red rays of the spectrum, so that most colored objects, viewed by it, appear of different colors than when illumined by ordinary daylight. It is claimed that for many purposes this is not an unmixed loss, since the light, although weak in the reds, is strong in the actinic rays at the opposite end of the spectrum, and is on this account easy on the eyes.

Description of Cooper Hewitt vapor lamp

Figure 216 represents the usual commercial types of the Cooper Hewitt mercury vapor lamp. The lamp consists, as shown, of a glass tube about 4 feet in length and an inch in diameter, exhausted to a high vacuum and hermetically sealed. The two ends of the tube are provided with bulbs, one of which, usually at the cathode end, is of considerable area, and forms what is called the *condensing chamber*. Platinum leading-in wires are sealed through the ends of the tube. The anode consists either of an iron grid or of a small quantity of mercury, according to the type of lamp. The cathodes, however, are always formed of mercury. The lamp may be hung in any position. It is operated by a direct current, usually of 3½ amperes, with a pressure for single lamps of from 50 to 150 volts. A number of lamps, however, may be connected together in series and run on a higher voltage.

Starting the lamp.

In the early history of this lamp, considerable difficulty was experienced owing to the exceedingly high resistance offered by cold mercury vapor to the passage of the electric current. This resistance, however, rapidly decreases as the mercury vapor becomes heated by the passage of the electric current. In the present forms of lamps, this difficulty has been greatly decreased by two methods for starting the lamp. These methods are called respectively the *quick break method* and the *tilting method*.

In the quick break method, as represented in the upper part of Fig. 217, the initial high resistance is

The quick break method.

broken down or decreased by means of a high-potential discharge from an inductance coil that is placed in series with the lamp. By closing a quick break switch placed in the circuit, as shown in the upper part of the figure, the circuit is completed through the inductances and resistances, thus charging the coil. On opening this circuit the discharge from the coil surges through the lamp, the current from the low voltage mains following in its wake.

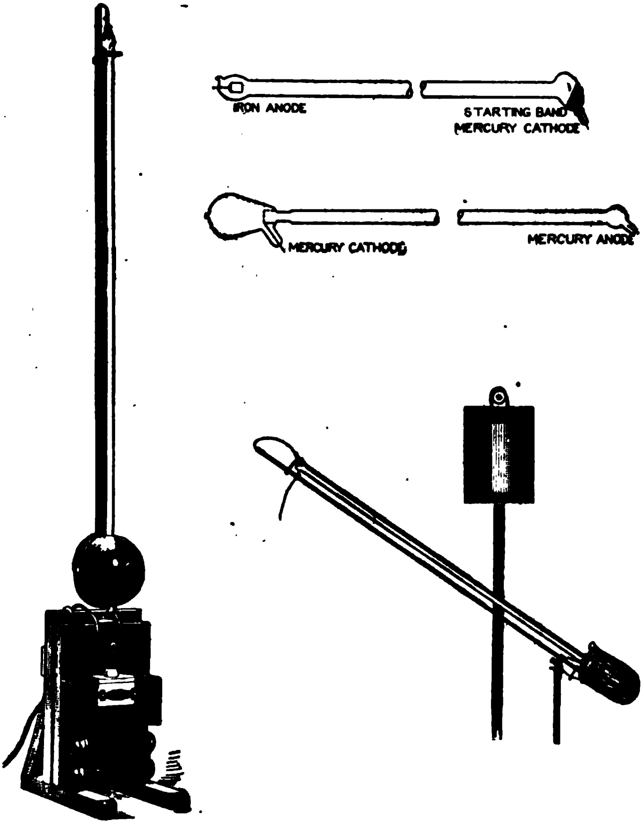


Fig. 216.—Forms of Hewitt Mercury Vapor Lamp. The upper cuts show the construction, and the lower ones the appearance, of types of the lamp.

A starting band of metallic paint placed around the cathode is employed with this method and connected with the anode, and assists in breaking down

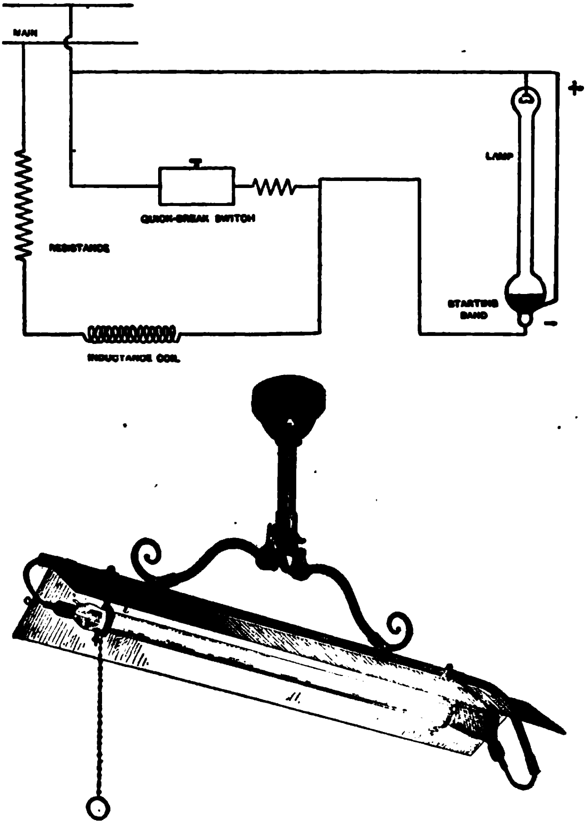


FIG. 217.—Methods of starting the lamp. The upper figure represents diagrammatically the high-tension discharge method, while the lower one shows a lamp operated by the tilting method, or "method of contact."

the high initial resistance, apparently by a sort of condenser action.

The tilting method.

The tilting method, or method of contact, as represented in the lower part of Fig. 217, constitutes the latest device for starting. The lamp holder is hung on a pivot held by means of a spring, so that one electrode is higher than the other. In order to start the lamp, the higher end is depressed by a chain until it contains an excess of mercury. When allowed to resume its former position, the mercury flows to the other end of the tube. In this manner connection is made momentarily between the electrodes, when, the mercury column breaking and changing into spray, the current jumps across the breaks and the light slowly ascends the tube.

Condensing chamber.

The condensing chamber, before referred to, automatically regulates the pressure of the mercury vapor within the tube, a certain pressure having been found to give the most efficient light. As this bulb is of comparatively large area, the heat is more quickly dissipated in it than in the main body of the tube. Hence, it is cooler, and the vapor entering it is condensed, thus decreasing the pressure in the lamp.

Prevention of flickering.

The electric current usually enters the surface of the mercury cathode at a single point. When this current dances around over the mercury an unsteadiness of the light is caused. In most cases, however, the leading-in wire is prolonged inside the cathode bulb so as to extend slightly above the mercury surface. Under these circumstances, the discharge of the current always takes place to the wire, and the dancing and unsteadiness disappear.

Fields of usefulness.

The Cooper Hewitt lamp has found extended use for lighting workshops, draughting rooms, etc., for advertising purposes and lighting showcases, and especially for photographic work. In this latter direction, both the diffusion of the light and the large proportion of chemically active rays render it a good substitute for daylight.

CHAPTER XXVII

VACUUM-TUBE LIGHTING

"Ideally, a gaseous radiant, with nearly its whole luminous energy concentrated in the visible spectrum, would give magnificent efficiency, but it by no means follows that it would give a good light."—*The Art of Illumination:* Louis Bell

Hawkesbee and his vacuum-tube lamp.

As early as 1709, Hawkesbee, to whom we have already referred, produced light by the passage of electric discharges through glass vessels containing rarefied air. This light was sufficiently bright to enable large print to be easily read. The subsequent development of the Geissler tubes and the induction coil made so great an improvement in the quantity of light emitted by vacuum tubes, that a number of inventors, since the time of Hawkesbee, endeavored to employ such vacuum tubes as sources of artificial illumination. We have already referred, in one of the preceding chapters, to the attempts of Greener and Staite in this direction.

Some advantages of vacuum-tube lamps.

The advantages possessed by a vacuum-tube lamp consist in the great length that can be readily given to the luminous tubes, and, consequently, the extended surfaces from which the light is emitted. This increase in the extent of the luminous surface permits of a uniformity of illumination that would otherwise be difficult to obtain. Moreover, with vacuum-tube lamps, it should be possible to ensure a great length of life in the lamps. It is claimed, too, that properly constructed vacuum tubes possess a much higher efficiency than the incandescing lamp.

The high efficiency claimed for vacuum-tube lamps is the natural result that would follow from the fact, as already pointed out, that, in such lamps, the energy is almost entirely converted into light energy, practically little or no heat energy being produced. In other words, the light of the vacuum-tube lamp is what may be called cold light. The high efficiency of the conversion of electric energy into light energy in the vacuum-tube lamp, arises from the fact that the electric discharge passes through the comparatively small quantity of air, or other residual gas in the tube, and thus raises it to an exceedingly high temperature; and it is the very fact of this high temperature that permits the tube to possess the characteristic of emitting cold light. Let us see how we can explain this apparent contradiction.

Vacuum-tube lamps cold luminous sources.

As we have already pointed out, as the mass of a carbon filament of a given area of cross-section decreases, that is, as its area of cross-section decreases, the temperature to which a given quantity of electricity is able to raise it, is increased. Now, in the case of the residual gas in the vacuum-tube, the mass or quantity is exceedingly small. Moreover, the possible temperature to which this small mass of gas can be raised is not limited, as it is in the case of the filament. Consequently, a given amount of electric energy is capable of raising the temperature to a much higher degree than would be possible in the case of a solid, with, however, this difference, that by far the greater amount of energy would appear in a form that is capable of affecting the eye, and a comparatively small amount in the form generally known as heat. Consequently, as the temperature of the gas is raised higher and higher, the quantity of light emitted increases, and

Why vacuum-tube lamps emit cold light.

the quantity of heat decreases, so that, at a certain temperature, the glowing gas may emit practically all light and no heat.

Objection to vacuum-tube lamps.

A practical difficulty that exists in all forms of vacuum-tube lighting, appears to arise from the fact that although the surfaces from which the light is emitted can be made very great, yet the actual quantity of light emitted appears, in most cases, to be comparatively small.

Moore and Tesla.

In America, both D. MacFarlane Moore and Nicola Tesla have, independently of each other, been working in order to produce practical forms of vacuum-tube lamps.

Moore vacuum-break.

The investigations of Mr. Moore, in vacuum-tube lamps, extend over seven or eight years. Mr. Moore first obtained the high E.M.F.'s, employed in lighting his vacuum-tubes, from the extra currents produced by suddenly breaking the circuit of electro-magnetic coils containing iron cores. This he did by connecting the terminals of the electro-magnet with constant-potential mains of 110 volts, and rapidly breaking the circuit of such coils by means of an automatic electro-magnetic break. This break he called a vacuum break or vibrator, from the fact that it was placed inside a vacuous space, in order to ensure a greater length of life and better operation. Moore employed, for his first form of vacuum-tube lamp, an ordinary incandescent lamp bulb, the arrangements of his circuits being such as are shown in Fig. 218.

In 1896, Moore substituted long glass vacuum tubes for the lamp bulb. He used these in connection with the same vacuum break, the connections being as shown in Fig. 219. Vacuum-tube lamps of this construction were employed in April, 1896, for the illumination of the meeting-room of the American Institute of Electrical Engineers, in New York, and also afterward, during the same year, for exhibition at the New York Electrical Exposition.

A difficulty, however, existed with the use of the vacuum-tube break, arising from the mechanical limitations of size, together with the fact that large installations required too many breaks. Believing that the peculiar advantages of this form of break were to be found in the particular character of the wave it produced, Moore afterward designed a form of dynamo capable of producing high E.M.F.'s, producing waves having an especial characteristic, and took out a patent for such generator in 1900. This form of Moore generator, which he called his vacuum rotator, is shown in Fig. 220, where it is seen as connected across constant-potential mains of 110 volts.

Moore's vacuum-rotator.

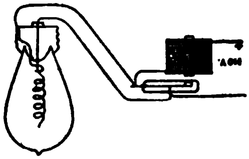


FIG. 218.—Moore Vacuum-tube Lamp, with vacuum break and lamp bulb.

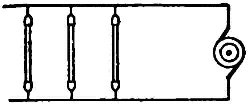


FIG. 219.—Moore Vacuum-tube Lamp. Vacuum break with long vacuum tube.

At a still later date, Mr. Moore invented means

Moore's direct use of alternating-current mains.

whereby the vacuum rotator could be dispensed with, and the tubes rendered luminous from electric currents taken directly from the alternating-current street circuits. This arrangement is shown in Fig. 221.

In describing the Moore vacuum-tube system, the "Electrical World," from which these pictures were taken, thus speaks of Mr. Moore's invention:

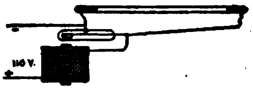


FIG. 220.—Moore's Vacuum-tube Lamp, with vacuum rotator.

Description of the Moore vacuum-tube system of electric lighting.

"Briefly stated, the invention claimed by Mr. Moore consists of distributing or running a translucent tube or receptacle over areas, spaces or rooms to be lighted, the terminals of the tube being brought to a source of energy outside of the areas or spaces, or in a location where the terminals may be suitably protected against danger of contact or accidental interference; the tube containing a gas which is of such character or degree of rarefaction, that, by the application of electrical energy or current to the terminals of the tube, it will be rendered luminous by the transfer of the energy from one terminal or electrode to the other. In the practical installation of the system, the translucent tube of glass may be built up in the position it is to occupy while in

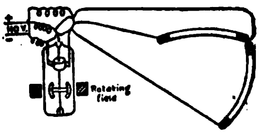


FIG. 221.—Moore Vacuum-tube Lamp, operated directly from alternating-current mains.

use, or otherwise distributed as a tube of glass over the spaces to be illuminated. Its terminals, which are provided with suitable energy transferring electrodes or caps, are brought to a protecting cabinet or wall pocket, in which they may be connected to the two poles of the energy supplying devices, the latter being mains or wires leading direct from the primary generator of E.M.F. These might be the terminals of suitable transformers adapted to give the required secondary voltage. In practice, alternating currents of greater or less voltage, as might be found desirable, would be used.

"For illuminating the interior of a dwelling or structure, the portions of the glass tubing, which contain the luminous column from which the effective illumination is obtained, would be distributed in any desired way throughout the whole interior of the dwelling or structure as one or more tubes, with the conducting caps or terminals thereof brought from within the illuminated spaces or areas to an exterior cabinet or receptacle where its conducting caps would be located out of harm's way, and in immediate connection with the source of energy. Or if desired, the energy might be carried into a building, and suitable transforming devices located in sealed wall pockets within the same, the terminals of the tube being located in the same manner in the pockets, while the luminous portion of the tube would extend over or through the areas to be lighted, being distributed in any desired form or manner therethrough."

Proposed use of long continuous illuminating tubes.

Nikola Tesla employed high-frequency discharges, obtained in various ways, either from direct or alternating currents, by charging and discharging condensers, and passing these discharges through the primary of an induction coil. High-frequency

Tesla's high-frequency discharges.

Light with and without electrodes.

discharges so obtained were caused to pass through vacuum tubes and produce light in the same. Tesla employed tubes both with and without electrodes, the mere bringing of a suitable tube in the presence of the discharges lighting it up with the characteristic vacuum-glow discharge. No actual installation of such lamps has ever been made on a large scale.

III

ELECTRIC POWER

CHAPTER XXVIII

EARLY HISTORY OF THE ELECTRIC MOTOR

> "The first attempts to obtain motive power from electricity were not successful. Many inventors spent large sums of money only to obtain insignificant results; and it was only when the reversibility of continuous current induction machines was tried that an advantageous solution of the problem could be looked for. Till then we had no electric currents sufficiently powerful to obtain any appreciable work."—*Electricity as a Motive Power*: Du Moncel

THE energy required for driving the machinery of the manufacturing plants that are employed in converting raw material into the varied finished products of commerce, was originally obtained from animal power; then wind and water power were added; and, afterward, the great invention of the steam engine gave a wonderful impetus to the manufacturing interests of the world. Where, however, mechanical power was taken either from a water wheel or a steam engine, the distances to which energy could be transmitted were limited. At the outset, where the transmission was limited to ropes and belts, the maximum distances were exceedingly small. Although afterward, when methods of pneumatic and hydraulic transmission were employed, such distances were considerably increased, yet it was not until the system of electric transmission was so perfected as to be properly re-

Various systems for the transmission of electric energy.

garded as an art, that the transmission of energy, over distances amounting to several hundred miles, became commercially possible.

Why a system of electric transmission of energy can successfully compete with any other system.

Where a waterfall is employed as a source of energy, the manufacturing plant is practically located at the waterfall. With electric transmission, however, the water power or steam engine can be located practically anywhere within reasonable limits, since, by converting the mechanical energy into electric energy by dynamos or generators, it can be transmitted through line wires or conductors to any point where it may be most convenient to utilize it. It is only necessary, at this distant point, to locate certain electric appliances in the shape of motors, etc., and to convert the electric into mechanical energy. The remarkably high efficiency and low cost of the electric motor, the readiness with which it can be controlled both as regards speed and power, the fact that it can be automatically made to take from the line wires or conductors only the amount of current required for its work, together with the numerous mechanical advantages it possesses, have enabled electric transmission successfully to compete with other methods of transmission, not only at long distances, but have even enabled it to successfully compete with transmission by belt shafting and pulleys in manufactories where the electric generator is situated in the same building with the driving machinery.

The electric transmission of energy is based on the fact that when an electric current, generated by an ordinary dynamo-electric machine, is passed through the circuit of a similar dynamo, this dynamo is caused to rotate, becoming an electric motor. In other words, the electric energy of the first dynamo is converted into mechanical energy by the second, so that the second dynamo can be employed to drive the machinery, just as could a steam engine, water wheel, or any other prime mover. In the case of the electric transmission of energy, the distance between the generator and the motor may vary from comparatively short distances to several hundred miles. Since the electric transmission of power is only rendered possible by the existence of the electric motor, it will be necessary to study in detail this important piece of electric apparatus.

Basis for the electric transmission of energy.

The electric motor was rendered possible by the great discovery of Oersted, in 1820, of the connection between electricity and magnetism. Long before this time various attempts were made to obtain continuous motion from the attraction and repulsion of permanent magnets for each other, or for masses of iron. But all these attempts failed because no means were then known of readily reversing, or changing, the polarity of magnetism. Consequently, as soon as a mass of iron, or other magnet, came in contact with the attracting magnetic pole, it remained there. Oersted, by showing how magnetic polarity could readily be changed or reversed, rendered it possible to cause such attractions or repulsions to produce continuous motion, and inventors were not slow in availing themselves of this discovery.

Electric motor rendered possible by Oersted's great discovery.

The first electric motor was invented by Faraday, in 1821, shortly after the announcement of Oersted's discovery. Faraday's early form of electric motor is shown in Fig. 222. It consisted, essentially, of an electric conductor so suspended as to be movable around the pole of a magnet. The magnet, in this case a permanent steel magnet, NS, was inserted, as shown, in a cork, which closed the bottom of a

Faraday's electric motor.

glass tube. A mass of mercury, or quicksilver, Q, was poured into this tube, so as to leave the magnet pole N projecting above its upper surface. A small conducting wire *ab* was so suspended at *a* as to be able to freely revolve around the pole N, with one of its ends dipping in the quicksilver. When an electric current was caused to flow through the wire *ab,* the wire revolved around the magnet pole N, this motion being caused by the interaction of the magnetic flux produced by the magnet and that produced by the electric current flowing through the conductor *ab*. The direction of this motion is dependent on the polarity of the magnet NS, as well as on the direction in which the current is flowing through *ab*. A change, either in the polarity of the magnet, or in the direction in which the current flows through the movable conductor, will cause a change in the direction of rotation of the conductor. If, for example, the conductor revolves around the magnet pole in the same direction as the hands of a clock, it will revolve in the opposite direction

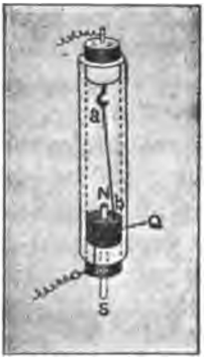


FIG. 222.—**Faraday's Early Electric Motor.** The forerunner of one of the most important of commercial electro receptive devices. Though exceedingly simple in its construction, yet this early motor contained the fundamental principles of the great electric motors of to-day.

Conditions of reversal of rotation of motor.

when either the magnet pole or the direction of current through the movable conductor is changed. If the conducting wire is fixed and the magnet is movable, the interaction of the magnetic flux will cause the magnet to revolve. This was actually done by Faraday in some of his early experiments.

First conception of electric motor claimed for Wollaston.

Puny and insignificant as was this early form of electric motor, yet it contained the germs of a great discovery, embodying, as it did, practically the fundamental principles of the electric motor of to-day. Like the growth of other great discoveries, the first conception of the electric motor was claimed for others. Indeed, it appears that the first to conceive the general idea that the principles of electro-magnetism, discovered by Oersted, could be employed for the production of electro-magnetic rotation, was Wollaston. Davy also appears to have made some experiments in this direction. Faraday acknowledges Wollaston's prior claim to the general idea, as will be shown from the following quotation from volume 2, page 159, of "Faraday's Experimental Researches in Electricity":

Faraday acknowledges Wollaston's claim to priority of conception of electric motor.

"Dr. Wollaston was, I believe, the person who first entertained the possibility of electro-magnetic rotation; and if I now understand aright, had that opinion very early after repeating Professor Oersted's experiments. It may have been about August, 1820, that Dr. Wollaston first conceived the possibility of making a wire in the voltaic circuit revolve on its own axis. There are circumstances which lead me to believe that I did not hear of this idea till November following; and it was at the beginning of the following year that Dr. Wollaston, provided with an apparatus he had made for the purpose, came to the Institution with Sir Humphry Davy to make an experiment of this kind. I

Experiments of Davy and Wollaston on electromagnetic rotation.

was not present at the experiment, nor did I see the apparatus, but I came in afterward, and assisted in making some further experiments on the rolling of wires on edges. I heard Dr. Wollaston's conversation at the time, and his expectation of making a wire revolve on its own axis; and I suggested (hastily and uselessly), as a delicate method of suspension, the hanging the needle from a magnet. I am not able to recollect, nor can I excite the memory of others to the recollection of the time when this took place. I believe it was in the beginning of 1821."

The two essential parts of every electric motor.

In the case of the electric motor, as in that of the dynamo, there are always two distinct parts to the machine; viz., the armature and the field magnets. As a rule, it is the armature that revolves and the field magnets that remain stationary. Sometimes, however, as in the case of dynamos, the field magnets revolve and the armature is stationary. In some motors, especially in those of the alternating-current type, it often becomes a difficult matter to distinguish which parts should receive the name of the armature and which that of the field magnets. In order to avoid this difficulty, the word stator is sometimes given to the part that remains mechanically fixed, and the word rotor to the part that is mechanically rotated, no matter what the magnetic relations of these parts may be.

Applying these principles to the preceding case, we find that, in Fig. 222, the conducting wire *ab* is the armature, and the permanent magnet NS is the field magnet.

The possibility of obtaining continuous motion by the mutual interaction of two separate magnetic fluxes having been thus demonstrated, many forms of electro-magnetic motors were produced, in which

A modified form of Faraday's early electric motor.

both permanent and electro-magnets were employed. Faraday himself made a variety of electric motors, one of which, a modification of his first apparatus, is shown in Fig. 223. Here, instead of having a single rotating wire or conductor, two such conductors were employed. A bar magnet AB, consisting of a bundle of separately magnetized bars, is placed in the vertical position shown, and has a rectangular conductor EF, rotatable about a metallic support D, resting on the magnet pole A. The rectangular circuit makes a continuous connection with the electric source, despite its rotation, by having its ends dipped below the surface of mercury in a circular vessel supported on a table M, as shown.

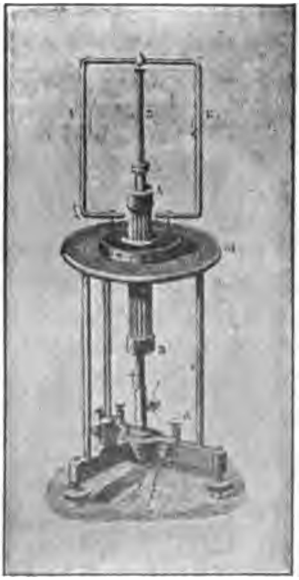


FIG. 223.—Another Form of Faraday's Early Electric Motor. Note the arrangement of the revolving armature, the rectangular circuit EF, and the field magnet AB. Note also the arrangement of the movable mercury contacts.

When an electric source, in this case a series-connected battery of four or five Bunsen cells, is connected with the binding post shown at the bottom of the figure, the current passing in the direction indicated by the arrows, flows through the magnet BA, through the metallic support D, where it divides through the branches F and E, of the movable rectangular circuit, which is then continuously rotated.

The next early electric motor of importance was that invented by Barlow, in 1831. Here a star-shaped wheel, which took the place of the movable conductors of the previous motors, was arranged so that the current from an electric source was conducted to the axis of the wheel, and passed out of the wheel where its points dipped below a mercury surface, as shown in Fig. 224. The trough containing this mercury is placed between the poles of a permanent magnet NS. As will be seen, this arrangement is not unlike those shown in the preceding figures, the movable conductor being here re-

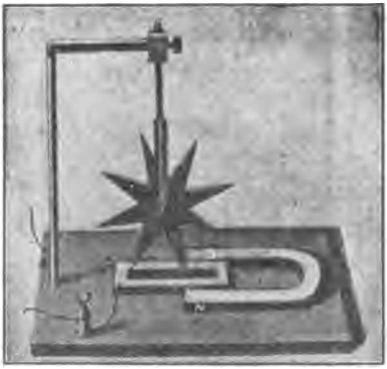


FIG. 224.—Barlow's Star-wheel Motor. Note the manner in which the current from a voltaic battery passes from the centre of the star-wheel through the radial arms by means of their contact with the mercury surface.

Barlow's star-shaped wheel motor.

placed by portions of the wheel lying between its axis and the point which dips into the mercury surface. As one point is thrown out of the mercury by the action of the electric motor, the momentum of the disk brings the next point into contact with the mercury surface, and so a continuous rotation is obtained.

Sturgeon's wheel, an early form of electric motor.

It will be evident that if, in place of passing the electric current through a star-shaped wheel, it be sent through a continuous metallic disk from the axis to the circumference, the circumference of which dips into the mercury surface, a continuous rotation will be produced. This was practically done by Sturgeon, who modified Barlow's apparatus in the manner shown in Fig. 225, where a disk placed between the poles N and S of a permanent magnet was caused to rotate by the passage of a current through it, by means of conducting wires + and —, brought into frictional contact with the axis and circumference respectively. Sturgeon's wheel was produced in 1823. It is practically the same as Faraday's early form of dynamo, and would have generated differences of potential, like an ordinary dynamo, had it been rotated on its axis by mechanical force. Had a current of electricity been sent through Faraday's disk dynamo, it would, like any

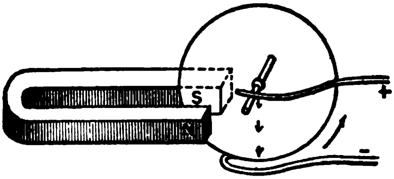


FIG. 225.—Sturgeon's Wheel, an early form of electric motor. Note the resemblances between this motor and that shown in the preceding figures. Much trouble was caused by the uncertain contact of the wire with the edge of the disk.

Sturgeon's wheel and Faraday's disk dynamo.

other dynamo-electric machine, have been caused to rotate by the current, or would have produced an electric motor.

Dal Negro's electric motor.

In 1832, Salvator dal Negro, Professor of Natural Philosophy in the University of Padua, published an account of means employed by him to produce continuous motion by electro-magnetism. In Dal Negro's motor, a permanent magnet took the place of the armature, being made to oscillate between the poles of electro-magnets employed as the field magnets. The poles of these electro-magnets were automatically changed at each movement, by the operation of a suitable commutator. By means of gearing and a crank these oscillatory motions were changed into a continuous motion.

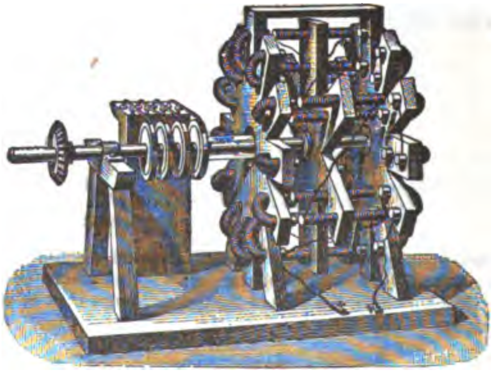


FIG. 226.—Jacobi's Electric Motor. Note that here electro-magnets are employed in both armature and field.

In 1834, Jacobi invented the electric motor shown in Fig. 226. Here the field magnets consisted of two circular rows, containing 12 separate horseshoe magnets, suitably supported, so as to face one another, and the current of an electric source was made to constantly pass through them, thus rendering them powerfully magnetic. Between these fixed magnets were supported a series of straight horseshoe magnets, attached to a star-shaped form of wheel, mounted on an axis, and capable of rapid rotation. These latter magnets constituted the armature. The circuit connections were such that metallic brushes, resting on the four commutator wheels, shown at the left-hand side of the figure, sent the electric current through the magnets of the armature, so as to cause them to be attracted by the fixed magnets, thus giving motion to the star-shaped support. When, however, the armature magnets came opposite the field magnets, the commutator changed the direction of the current in the armature magnets, thus permitting the stationary magnets to repel them. In this way a continuous rotation of the wheel was produced.

Operation of Jacobi's electric motor.

Jacobi's electric motor produced considerable excitement in Russia at the time it was first publicly tried. In 1834, the Emperor of Russia provided Jacobi with funds for the construction of a larger machine. It was with this latter machine that Jacobi succeeded in driving a large rowing-boat, by means of paddle-wheels, rotated by his motor. The following description of this motor is given by Du Moncel, in his "Electricity as a Motive Power":

Jacobi aided by the Emperor of Russia.

"The boat employed by him was a ten-oared rowing-boat, fitted with paddle-wheels rotated by his electro-magnetic machine. The boat carried ten or twelve people, and the runs sometimes lasted the whole day. . . The difficulties that he met with in the electric generator, and the imperfections in the construction of the motor, often caused breakdowns which it was difficult to remedy on the spot. However, when they were overcome, Jacobi was able to

Jacobi's electrically propelled boat.

estimate the work produced, and he showed that a battery of platinum plates of 20 square feet surface could, by this means, be made to develop one horse-power; but he always hoped to obtain the same result with half this battery surface. The boat, according to report, went about four miles an hour, being a better result than that obtained at the first trials of small steamboats. According to Jacobi, the boat was 28 feet in length, 7 feet 6 inches in beam, with a draught of water of 2 feet 9 inches. At the experiments in 1859, the machine, which occupied a small space, was worked by a battery of 64 platinum cells, each having 36 square inches of surface, and charged, on the Grove system, with nitric acid and acidulated water. When the boat, with twelve or fourteen people on board, went against stream, she could make three miles an hour."

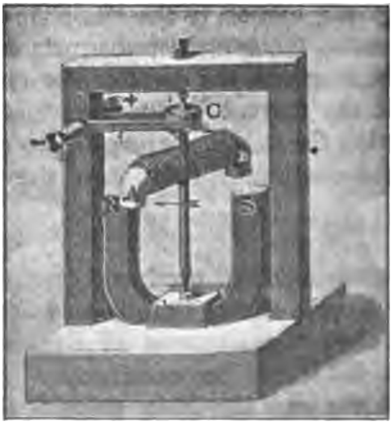


FIG. 227.—Ritchie's Electro-magnetic Motor. Note the revolving armature in the form of the electro-magnet AB.

In 1834, Ritchie, in America, invented the form of electro-magnetic motor shown in Fig. 227. Here the field magnet consists of a permanent magnet

NS, in the shape of a horseshoe. The armature is formed by an electro-magnet, AB, wrapped with coils of insulated wire, and so mounted as to be capable of rotation on a vertical axis above the poles N and S of the field magnet. A commutator at C changes the direction of the current twice during each complete rotation. If the circuit connections are such that, in the position shown in the figure, the pole A of the armature is made to acquire south magnetic polarity, and B north magnetic polarity, then the mutual attraction between the poles of the armature and the field will cause the armature to move in the direction indicated by the arrow. But at this moment the direction of the current through the coils on the armature is reversed, so that the poles of the armature now become of the same polarity. Since the momentum, or tendency of the armature to keep on moving, carries it a short distance past the poles of the field magnet, the motion is continued by the repulsion between these poles, which causes it to rotate until the pole A is brought within the attractive influence of S, and B within the influence of N. In this manner a continuous rotation is effected. The commutator C is employed for changing the direction of the current.

Ritchie's electro-magnetic motor.

Manner in which the Ritchie motor operates.

In 1837, Thomas Davenport, a Vermont blacksmith, produced an electric motor which he successfully employed for driving a printing press, as well as for operating a circular electric railway at Springfield, Mass. Davenport constructed several forms of electro-magnetic motors, one of which consisted of a series of fixed electro-magnets for the field magnets, and movable electro-magnets for the armature. This motor, when running light, was capable of producing 600 revolutions per minute.

Davenport's electric motor.

Davidson's electric motor.

In 1839, Robert Davidson, a Scotchman, operated both a lathe and a small locomotive, by means of an electric motor of his invention. With this motor he was able to run a locomotive, carrying two people, over a rough plank road, at a speed of four miles per hour, when his motor was traversed by a current from a battery of 40 separate voltaic cells.

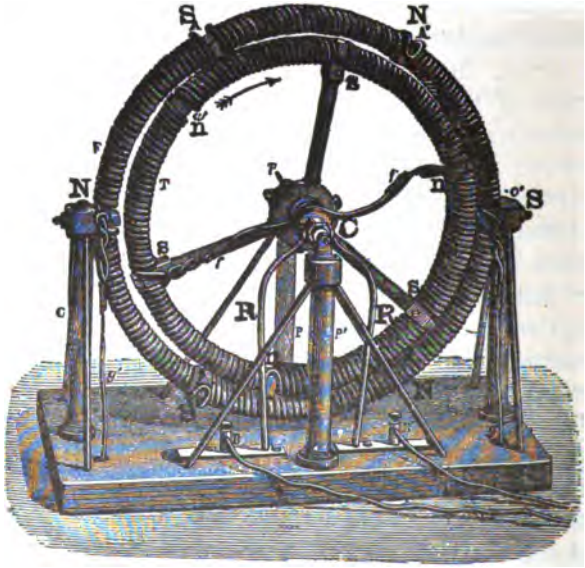


FIG. 228.—The Elias Electric Motor. Note the arrangement of the poles N,S, N,S, N,S, and *n,s, n,s, n,s,* etc. Note also that both field and armature magnets are electro-magnets.

Elias's electric motor.

In 1842, Elias, of Haarlem, invented a form of electric motor which showed various marked improvements over pre-existing forms. The Elias motor is shown in Fig. 228. Here the field magnets consist of a circular ring of soft iron. This ring was wrapped with coils of insulated wire, so that, when traversed by a current, it produced six poles of alternately opposite polarity, at

N, S, N, S, N, S. The armature consisted of a similar iron ring wound with coils of insulated wire, so as to produce six magnet poles of alternately opposite polarity, at *n, s, n, s, n, s*. The armature was mounted on a horizontal axis, so as to be capable of rotation within the field magnets. The Elias motor, like that of Jacobi, employed electro-magnets both for the field and the armature. It was, as will be seen, a sexti-polar machine; that is, one whose field magnets consist of six separate magnet poles. The commutator C was employed for changing the polarity of the armature coils at the proper moment, in order to permit continuous rotation. It differed also in that it formed a motor in which the field magnets were separately excited, a separate and distinct battery being employed for maintaining the magnetism of the field magnet.

Employs electro-magnets for both field and armature.

In 1845, Froment, of France, constructed the electric motor shown in Fig. 229. Here the field magnets consisted of four electro-magnets of the horseshoe type, each electro-magnet consisting of two separate coils. The armature consisted of a wheel of brass, or other non-magnetic material, supported on a horizontal axis, so as to be capable of rotation before the poles of the electro-magnets. To the circumference of this non-magnetic wheel were attached a number of bars of soft iron, which acted as the armatures of the different electro-magnets as the wheel successively passed them in its rotation. A commutator was placed on the shaft of the armature, which caused them to acquire and lose their magnetism at the proper time, and thus produced continuous rotation of the armature.

One of Froment's electric motors.

Froment produced several other forms of electric motors, one of which is shown in Fig. 230. Here, in reality, the motor belongs to the type of machine in which the field magnets are revolved and the armature remains stationary. In other words, the rotor consists of ten horseshoe electro-magnets, mounted on a horizontal shaft, so as to rotate readily within a rigid ring of gun metal, which bears on its inner face 12 bars of soft iron, which act as the armatures of the rotating electro-magnets. It will be observed that the axis of rotation is not concentric with the axis of the non-magnetic ring bearing the soft iron armatures. A commutator is provided to introduce or remove the magnets from the circuit at the proper time, so that, in this way, a continuous motion is obtained.

Another form of Froment's electric motors.

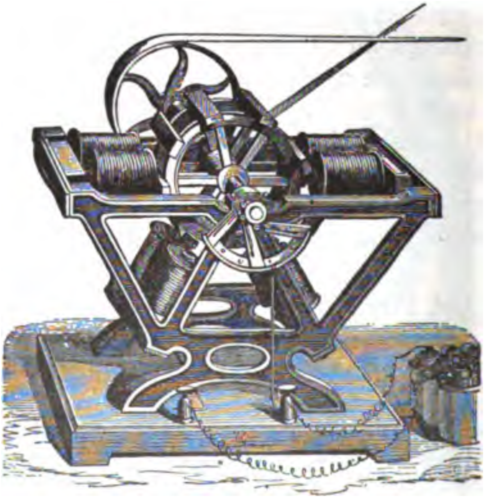


Fig. 229.—One of Froment's Electric Motors. Note the construction of the armature, which consists of bars of soft iron, rendered magnetic by induction from the electro-magnetic field poles.

In 1850, Prof. C. G. Page, of the Smithsonian Institution, of Washington, D. C., invented a form of electric motor, the field magnets of which consisted of a pair of solenoidal coils, and the armature was formed by cores of soft iron that were attracted or drawn into the solenoidal coils when the current was sent through them. As soon as the core passed half-way through the coil, a commutator cut it off from this coil and sent it through the other coil, so that the other core was then drawn into this coil.

Page's electric motor.

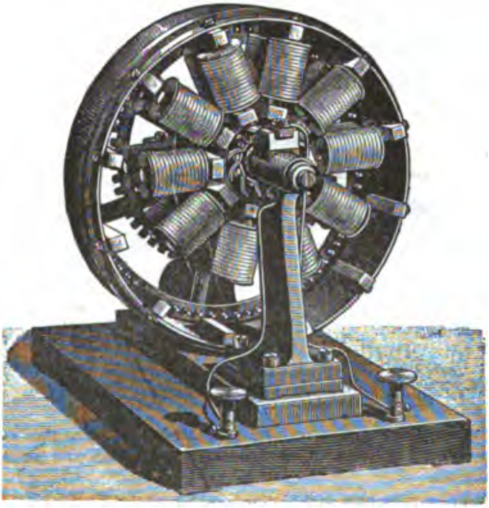


Fig. 230.—Another of Froment's Electric Motors. Note the fact that the axis about which the revolving field rotates is not concentric with the fixed ring-shaped armature.

A form of Page's electric motor is shown in Fig. 231, where A and B are the two solenoidal coils, and C and D the two soft iron cores. These cores are counterbalanced on the end of a beam GFI, and connected with GH, the connecting rod HK, and the crank K, like the working beam of a steam engine. The cut-off, arranged to send the current alternately through the different solenoids, is operated by the eccentric L, like the eccentric of a steam engine. A locomotive engine was successfully driven on a track by Page in 1851. It did not, however, prove a success.

Page constructed a large motor, which he employed to drive a locomotive on the Baltimore & Ohio Railroad tracks, in the United States, on the 29th of April, 1851. This locomotive made a trip between Washington and Bladensburg, a total distance of ten miles. Page employed for the battery, to drive this motor, 100 cells of Grove's nitric acid battery. On this trial trip a speed of 19 miles an hour was maintained for a distance of nearly one mile, on a part of the road that was fairly level. Unfortunately, on account of the jolting of the car, one of his battery cells cracked, thus permitting the acids to mingle and materially lessening the speed. Although on this trip there were some seven halts made, consuming about 40 minutes of time, yet the entire distance to and from Washington and Bladensburg was made in one minute less than two hours. Difficulties, however, arose in practice from slight irregularities in the roadbed producing either a spilling of the acids in the battery, or a breaking of the

Page's trial of electric locomotive on tracks of the B. & O. R. R. between Washington, D. C., and Bladensburg.

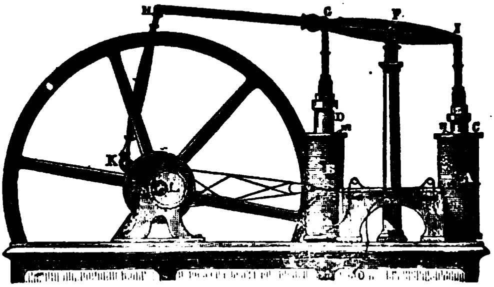


FIG. 231.—Page's Electro-magnetic Motor. Note the resemblances between this early form of electro-magnetic engine and an old form of steam engine.

cells, so that Page's effort to produce practical electric traction was a failure.

The lack of success that attended Page's effort to apply electric motors to the driving of surface railroad cars does not seem to have deterred other inventors from endeavoring to improve on pre-existing motors, and numerous inventions were made in this direction in various parts of the world. We will describe but one of these; viz., that made in 1861, by an Italian named Pacinotti. Pacinotti's motor was a marked advance on anything that preceded it. It is represented in Fig. 232. The armature consisted of an iron ring, furnished with a number of equidistant teeth, which had coils of insulated wire wound in the spaces between contiguous teeth. This armature was suspended by four brass arms B, B, so as to be capable of rotation between the pole pieces A, A, of two electro-magnets L, L′. The ends of the coils were connected to a commutator not unlike that of the Gramme dynamo machine.

Pacinotti's electric motor.

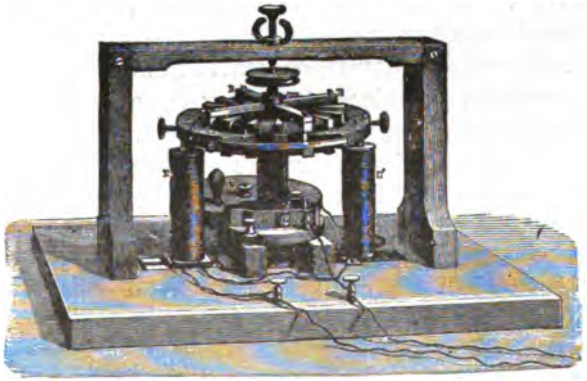


FIG. 232.—Pacinotti's Electric Motor. Note the fact that this form is an early forerunner of the Gramme dynamo electric machine.

By means of this commutator, a continuous rotation of the armature was obtained.

Reason for commercial failure of early electric motors.

As was to be expected, nothing came from any of these early forms of electric motors, since there was not yet any successful method devised, other than voltaic batteries, for commercially producing the currents required to drive the motors. Although the dynamo-electric machine had been invented by Faraday, yet it had not been sufficiently developed to enable inventors to employ it for a producer of current. When, however, about 1871, the Gramme dynamo-electric machine was commercially introduced, and it began to be generally known that such a machine, as indeed any other dynamo, was capable of acting as a motor as well as a generator, the advantages of electric motors began again to attract the attention of inventors in different parts of the world, and from this time on the production of new and efficient forms of electric motors was markedly increased.

Discovery of reversibility of dynamo and motor.

Early knowledge of reversibility of dynamo.

But one of the most important things in the early history of the electric motor was the discovery, before alluded to, that the same machine is capable of acting either as a generator or as a motor. It is not exactly known to whom should be given the credit for this valuable discovery. It was certainly known by Lenz, in 1838, when he announced his law, already referred to. Jacobi knew it in 1848. Pacinotti called especial attention to it in connection with the electric motor shown in Fig. 232. Siemens appears to have been acquainted with the fact in 1867, and, besides this, various other writers have referred to the matter. It was not, however, until the time of the Vienna Universal Exposition, in 1873, that this fact became generally known. During this exposition a Gramme dynamo-electric machine was driven as a motor by means of the current produced by a second Gramme dynamo-electric machine. Fontaine, in a communication to a French society, appears to claim this discovery for himself, although, from what has been said before, it is clear that the fact was known long before this time:

Fontaine's claim of invention of reversibility of dynamo.

"On the 1st of May, 1873—that is, on the date fixed four years previously by imperial decree—the Exhibition in Vienna was formally opened. At that time the machinery hall was yet incomplete, and remained closed to the public until the 3d of June, when it was also thrown open. I was then engaged with the arrangement of a series of exhibits, shown for the first time in public, which were intended to work together, or separately, as desired. There was a dynamo machine, by Gramme, for electroplating, giving a current of 400 ampères at 25 volts, and a magneto machine, which I intended to work as a motor from a primary battery, or from a Planté accumulator, to demonstrate the reversibility of the Gramme dynamo. There were also a steam engine, of my invention, heated by coke, a domestic motor of the same type heated by gas, a centrifugal pump placed on a large reservoir, and arranged to feed an artificial cascade, and numerous other exhibits. To vary the experiments I proposed to show, I had arranged the pump in such a way that it could be worked either by the Gramme magneto machine or by the steam engines (Fontaine).

Some details of Fontaine's exhibit.

"On the 1st of June it was announced that the machinery hall would be formally opened by the Emperor at 10 A.M. on June 3d. Nothing was then in readiness, but those who have been in similar situations know how much can be got into order in the space of forty-eight hours just before the opening of a great exhibition. In every department

Exhibition to open in 48 hours and very little ready.

members of the staff with an army of workmen under their orders were busy clearing away packing cases and decorating the spaces allotted to the different nations. These gentlemen visited all the exhibits in order to determine which of them should be selected for special notice of the Emperor, so as to detain him as long as possible among the exhibitors of their respective countries.

"M. Roullex-Duggage, who superintended the work in the French section, asked me to set in motion all the machinery on my stand, and especially the two Gramme machines. I set about at once, and on the 2d of June I had the satisfaction of getting the large Gramme dynamo, the two engines (Fontaine), and the centrifugal pump to work; but I failed to get the motor into action from the primary or secondary battery. This was a great disappointment, especially as it prevented my showing the reversibility of the Gramme machine. I was puzzled the whole of the evening and the whole of the night to find a means to accomplish my object, and it was only in the morning of the 3d of June, a few hours before the visit of the Emperor, that the idea struck me to work the small machine by means of a derived circuit from the large machine. Since I had no leads for that purpose, I applied to the representative of Messrs. Manhis, of Lyons, who was kind enough to lend 250 metres of cable, and when I saw that the magneto machine was not only set in motion, but developed so much power as to throw the water from the pump beyond the reservoir, I added more cable until the flow of water became normal. The total length of cable in circuit was then over two kilometres. This great length gave me the idea that by the employment of two Gramme machines it would be possible to transmit mechanical energy to great distances. I spoke

An inspiration at the last moment

of this idea to various people, and I published it in the 'Revue Industrielle' in 1873, and subsequently in my book on the Vienna Exhibition. The publicity thus given to it was so great that I had neither time nor desire to protect my invention by a patent. **No patent.** I must also mention that M. Gramme has told me that he had already worked one dynamo by the other, and I have always held that the honor of my experiment belongs to the Gramme Company."

CHAPTER XXIX

ELEMENTARY PRINCIPLES OF THE ELECTRO-MAGNETIC MOTOR

> "The 'why' is plain as way to parish church."
> —*As You Like It,* Act II, Scene VII

Electro-dynamic force.

THE motions of electro-magnetic motors are due to the operation of a force called the electro-dynamic force, produced by the interaction of the magnetic flux of the field magnets and the magnetic flux of the active wires or conductors on the armatures. In other words, the operation of such motors is based on the principles of electro-dynamics, investigated by Ampère shortly after Oersted's announcement of his discovery of the relations between electricity and magnetism. These laws, to which reference has already been made, may be briefly stated as follows: Two neighboring, movable electric conductors attract each other when the electric currents passing through them flow in the same direction, and repel each other when such currents flow in opposite directions. These directions of attraction and repulsion are due to the attraction and repulsion of their magnetic fluxes, which will be oppositely directed between neighboring conductors through which currents are flowing in the same direction, and similarly directed between such conductors when their currents are flowing in opposite directions. The law, therefore, for the attraction and repulsion of movable, active conductors can be generally stated as follows: Cur-

General laws of electro-dynamics.

rents flowing in the same direction through two neighboring, movable electric conductors attract each other because the magnetic fluxes between them are oppositely directed; while two movable, active, neighboring conductors repel each other when their currents flow in opposite directions, because the magnetic fluxes between them are then similarly directed.

Reasons for attraction and repulsion of neighboring movable electric conductors.

Bearing in mind the fact that the electric current flowing through the conductor AB, shown at the bottom of Fig. 233, from A to B, produces circular magnetic flux around it in a clock-wise direction, as indicated by the circular arrows, it will be seen, if such conductor be placed in the uniform magnetic flux represented by the small arrows, so that the flux in which the conductor is placed will have the same direction as that produced by the conductor in the space above such conductor, and will have the oppo-

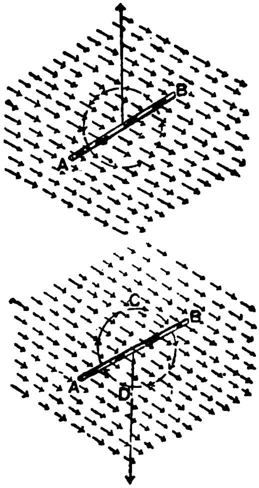


Fig. 233.—Direction in which the Electro-dynamic Force Acts.

The cause of the development of the electro-dynamic force.

site direction to such flux in the space below the conductor, this difference in the amount of flux on different sides of the conductor will result in the production of a mechanical force, called the electro-dynamic force, which tends to move the wire downward in the direction of the large arrow. If the direction of the current through the conductor AB be reversed, so that the current passes as indicated at the top of the figure, from B to A, then the direction of the circular magnetic flux will be counter-clockwise, so that the flux is denser below the conductor than it is above it, and the electro-dynamic force will tend to move the conductor upward in the direction indicated by the large arrow. Bearing this explanation in mind, it is easy to see why changing the direction of either of the magnetic fluxes will change the direction of the electro-dynamic force, while changing the direction of both of these fluxes will have no effect in the direction of the electro-dynamic force.

How reversal of the direction of one of the fluxes will change the direction of the electro-dynamic force.

Since the conducting wires through which electric currents are passing are necessarily in the form of a complete circuit or loop, ABCD, as shown in Fig. 234, the motions before referred to may be generally stated as always taking place in such directions, under the action of the electro-dynamic force, as to cause the conducting loop to move into a place in which it embraces the greatest possible quantity of flux; *i.e.,* until it takes the position shown by the dotted lines *abcd,* in the aforesaid figure. As soon as this is done the motion of the loop ceases, so that, in order to make the motion continuous, it is necessary to change the direction of the flux, which is done by changing the direction of the current in the coils. In every case, however, the loop will move in such a direction as will tend to bring its own flux

Tendency of movement to place interacting fluxes parallel to each other.

parallel to the flux of the magnetic field in which it has been placed.

A modern form of a continuous-current electro-magnetic motor is shown in Fig. 235. This is a bipolar motor, the field magnets consisting of two magnetizing coils M,M, that produce two field poles N, S. The armature A consists of a laminated iron core, wound with coils of insulated wire, practically in the shape of the conducting loop shown in Fig. 234. The armature loops are, therefore, placed in the magnetic flux produced by the magnet poles N, S, which, as we have already seen, will pass out of the north pole and enter the south pole. Brushes B, B rest on the commutator C, in the position shown. These brushes supply the current to the armature from the main terminals T, T, so as to produce north and south poles of *n*, *s*, approximately midway between the field poles N, S. The armature is pulled around by the electro-dynamic force produced in the conducting loops, and the commutator changes the direction of the current in these loops in such a manner as to permit of the production of a continuous rotation.

Bipolar motor for continuous or direct electric currents.

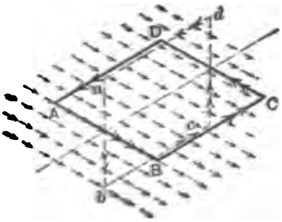


FIG. 234.—Development of Electro-dynamic Force in Active Conducting Loop.

The value or strength of the electro-dynamic force produced depends on the following circum-

Circumstances determining the strength of the electro-dynamic force.

stances: viz., on the strength of the current passing through the conducting loops, that is, on the strength of the current driving the motor; on the size and number of such conducting loops, or on the amount of the magnetic flux which the loops embrace; and on the strength of the magnetic flux in which the conducting loops are placed. In other words, the amount of the pull produced on the armature of an electric motor, or, as it is generally called, its torque, will depend on the strength of the current passing through the armature, on the amount of magnetic flux passing through the conducting loops on the armature, and on the number of such conducting loops.

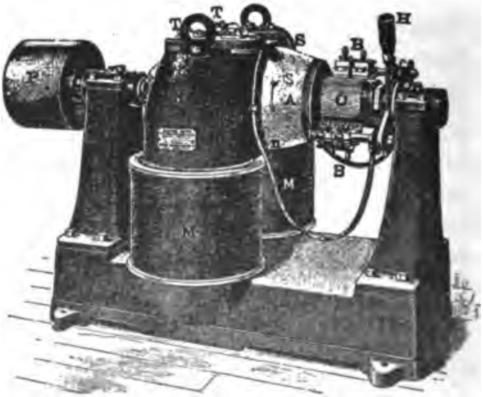


Fig. 235.—Bipolar Electric Motor for Continuous Currents. Note the powerful field magnets with their magnetizing coils and the armature which is rotated between their powerful pole pieces under the influence of the electro-dynamic force.

Power of motor dependent on torque and speed.

The power which an electric motor is able to exert depends on the torque which its armature produces, and on the speed with which it runs. It will be necessary, therefore, to inquire into the circumstances that determine the speed at which a motor runs.

Since all electric motors are reversible, that is, are able to produce differences of potential or E.M.F.'s when rotated, it is clear that while the armature is being driven by the passage of the electric current, it must act as a dynamo armature producing an E.M.F. in the opposite direction to the E.M.F. that sets up the driving current. The E.M.F. thus produced by the motor armature is called the counter electro-motive force, or the C.E.M.F. This C.E.M.F. tends to oppose the current strength which the motor receives from the mains that supply it with the driving current. The higher the speed at which the armature runs, other conditions remaining the same, the greater is the value of this C.E.M.F., consequently the smaller is the current strength the motor receives from the mains. In all cases, the armature attains such a speed, while in operation, as will limit the current received to the exact value required to produce the torque necessary to enable the motor to do the work given to it. If this amount of work be increased; *i.e.*, if an additional load be placed on the motor, its speed will decrease, the value of the C.E.M.F. will correspondingly decrease, and a greater amount of driving current will be permitted to pass through the armature coils. Hence the torque will increase until the motor is enabled to do the work placed on it.

Counter-electro-motive force of motor.

Great value of the C.E.M.F. of electric motor.

If the number of conducting loops on the armature of a separately excited motor be large, and these loops be of small diameter, then, if such motor be connected with a pair of constant-potential mains, its speed will be comparatively slow, since the C.E.M.F. it can produce at a given speed will be comparatively great; but if, on the contrary, the number of conducting loops on the armature be small, especially if they be of great diameter and

Armature resistance and motor speed.

small resistance, then the speed of the motor, when connected with constant-potential mains, will be great, since it must attain comparatively a high speed in order to produce the necessary C.E.M.F. If the resistance of the armature be high, then, when an increased load is placed on the motor, the amount of change in the speed of the motor, necessary to permit the increased amount of current to pass through it, will be great, so that the speed must decrease considerably. On the other hand, if the resistance of the motor be low, only a small decrease in speed will be necessary in order to permit the correspondingly large increase in driving current to pass. If the pressure on the driving mains is increased, the speed of the motor will also increase, in order to develop the necessary C.E.M.F.

Effect of variations in the field flux on the speed of rotation of the motor.

If the amount of magnetic flux passing through the armature of the motor be varied, and not maintained constant, as has been supposed in the above cases, then the speed of the motor will vary with variations in the amount of flux passing. Since the armature will increase in speed until the necessary C.E.M.F. is produced, it is evident that, by weakening the field by decreasing the current strength passing through the field magnets, we must increase the speed of rotation. On the contrary, by increasing the amount of flux passing through the field by increasing the current strength passing through the field magnets, we will correspondingly decrease the speed of the motor.

CHAPTER XXX

SOME FORMS OF CONTINUOUS-CURRENT MOTORS

"Almost any good modern dynamo (independently excited, shunt wound, or compound wound) will serve as a motor on mains supplied at the proper pressure; but attention has to be paid to the setting of the brushes that it may run rightly, and the machine so used must be one that will give the proper voltage at the proper speed. In designing motors precisely the same principles hold good as obtain for designing generators; for the same features, namely, low internal resistance, powerful field-magnets, and proper elimination of eddy-currents, which go to make a good generator, also apply to the making of a good motor."—*Dynamo-Electric Machinery*: S. P. THOMPSON

IN order to maintain a constant amount of magnetic flux in the field magnets of the electric motor, the plan is sometimes adopted of furnishing a separate source of current for their field magnet coils; that is, to employ separately excited motors. Generally, however, it is more convenient to place the motors across constant-potential mains, in which case, since the resistance of the armature coils remains constant, the current strength in the field magnet coils, and, consequently, the magnetic flux which the field magnets produce, will also remain constant.

Separately excited motors.

Continuous-current motors can be divided into three different classes, according to the connections between the field magnet and the armature circuits, or according to the number of coils of wire on the field magnet cores. These three classes are shunt-wound motors, series-wound motors, and compound-wound motors. It will be noticed that the differ-

Shunt-wound, series-wound, and compound-wound motors.

ent classes of motors are practically the same as the corresponding classes of shunt-wound, series-wound, and compound-wound dynamos or generators.

Shunt-wound electric motor.

A shunt-wound continuous-current motor is shown in Fig. 236. Here, as in the case of the shunt-wound dynamo, the field magnet coils M are connected in shunt through *d* and *e*, with the armature coils A. The current strength which the mains will be able to pass through the armature will depend on whether the armature is in motion or at rest, while the amount of current that the armature can continuously take at full load will depend on its size, on the character of its winding, and on its general construction. A shunt-wound motor possesses a self-governing power, which corresponds to the self-regulating power of the shunt-wound dynamo. A shunt dynamo, when driven at a constant speed, produces a nearly constant potential at its terminals, while a shunt-wound motor, if supplied with a nearly constant potential, will furnish mechanical power at a nearly constant speed, the variations in the constancy, in both cases, depending on the resistance of the armature, together, in the case of the motor, with the amount of mechanical power generated, and in the case of the dynamo, with the amount of electric energy produced at any particular time.

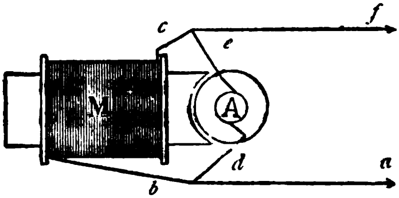


FIG. 236.—Diagram showing Connections of Shunt-wound Motor.

Self-governing power of shunt-wound motor.

The shunt-wound motor is the commonest form of stationary electric motor. It has, in general, a speed that is constant under different loads, but the speed can readily be changed when so desired, either by varying the number of turns in series on the armature, the strength of the field magnets, or the value of the E.M.F. applied to the armature.

Series-wound electric motor.

A series-wound continuous-current motor is represented in Fig. 237. Here the magnet coils M are connected in series with the armature A, between the constant-potential mains *a* and *f*, by means of the conducting wires shown. In this case the amount of current flowing through the field coils will vary with the value of the C.E.M.F. produced by the armature, so that, when the load on the machine is small, the current strength will also be small, and the amount of flux passing through the armature will be correspondingly small, so that the motor will run at a comparatively high speed. As, however, the load increases, the current passing through the motor will increase, and with the increase in the magnetic flux so produced, the motor will run at a slower speed. A series-wound motor is, therefore, far more variable in its speed than a shunt-wound motor. Its advantage, however, is to be found in the fact that, in small sizes, it is much simpler to construct, and is, therefore, cheaper.

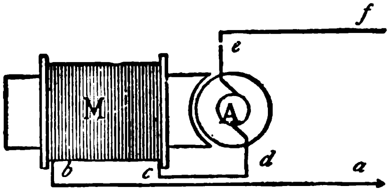


FIG. 237.—Diagram showing Connections of Series-wound Motor.

Compound-wound electric motor.

Self-governing power of compound-wound motor.

A compound-wound continuous-current motor is shown in Fig. 238, where the armature is connected in series with the coarse wire coil *m*, while the armature and this coil are connected in shunt with the fine wire coil M. The windings of *m* and M oppose each other; *i.e.*, the shunt coil M tends to magnetize the field, while the series coil *m* tends to demagnetize it. Where a shunt motor, such, for example, as that described in connection with Fig. 236, supplied by constant-potential mains, and having a certain speed at a given load, has its load suddenly removed, it will begin to run at a high speed, which will continue until the C.E.M.F., developed by the rotation, cuts down the armature current. By reason, however, of the resistance of the armature, this cutting down is not sufficient to enable the motor to regain its proper speed. With the use of the demagnetizing series coil *m* wound on the field magnets, the magnetic flux passing through the armature becomes slightly weakened at full load. The slight acceleration in the speed of the armature necessary to develop the required C.E.M.F. may be so adjusted as almost to completely make up for the decrease in speed that would otherwise take place by reason of the drop of pressure in the armature acting as a separately-excited machine. By these means a compound-wound motor may become self-governing, and may, therefore, be so adjusted as to run at a practically constant speed under all loads.

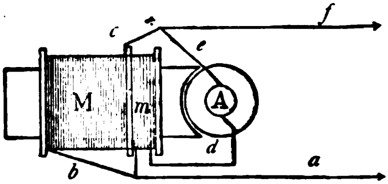


FIG. 238.—Diagram showing Connections of Compound-wound Motor.

Efficiency of continuous current motors.

A continuous-current motor can be made to have a very high efficiency; for, while a very small motor, of say but the fraction of a horse-power, may not have an efficiency of more than about 30 per cent, yet a 1-horse-power motor may have an efficiency of 60 per cent, a 2½-horse-power motor an efficiency of 81 per cent, and a 100-horse-power motor an efficiency of 90 per cent, or even greater.

Some of the advantages of electric motors.

Electric motors possess many advantages over steam engines for the purposes of driving machinery. In addition to the high efficiency above mentioned, the electric motor is much more compact, and is of simpler construction than the steam engine. It, consequently, requires less attention and fewer repairs. But what renders the electric motor so extremely valuable is the fact that it can be made automatically self-governing, as already explained; that it employs a rotary motion, in contradistinction to the reciprocating motion of the ordinary steam engine. Then again, the ease with which the electric motor can be installed or placed in position to do its work, is far greater than in the case of the steam engine; for, instead of requiring a system of steam pipes, the length of which is necessarily limited, it only requires connection with the supply mains by means of insulated conductors. Moreover, in addition to the above, electric motors can be directly coupled to the driving shaft of the machine which they are intended to operate, thus doing away with belting and shafting, and decreasing greatly the mechanical loss due to the friction of the belting and shafting. It is on account of these advantages that electric motors are rapidly coming into use for the driving of all kinds of machinery, even under circumstances where the electric genera-

Rapid extension of direct motor-driven machinery.

tors are practically placed in the same building with the electric motors employed to drive the machinery.

Use of motors on constant-current and constant-potential mains.

Electric motors can be employed either on constant-current circuits or on constant-potential circuits. In the case of constant-current circuits, the motors are series-wound, and are so arranged that their speeds can not become excessive. Continuous-current motors are not generally operated at pressures greater than 1,000 volts, although they have been operated at many times this pressure. A series-wound motor will, like any other motor, whether separately excited, shunt-wound, or compound-wound, give a constant pull on its shaft when supplied with a constant pressure by connection across constant-potential mains. But this is only true where a single motor is thus connected across such mains. Where several motors are thus connected in series, as in Fig. 239, where two series-wound motors are shown so connected, their speeds will tend to be very irregular; for, if the load on either machine varies even slightly, say slightly increases, there is at once produced a tendency to slow down the overloaded motor, and increase the speed of the

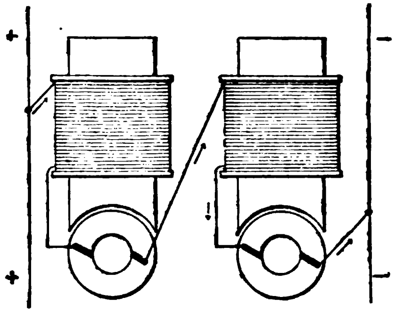


FIG. 239.—Connection of two Series-wound Motors in Series Across Constant-potential Mains.

Series-connected series motors across constant-potential mains.

more lightly loaded motor. In order to avoid this, it is necessary to rigidly connect the motors so that their speeds will be the same, and that they will act as a single motor. Where a series motor is operated on a series circuit, some device is necessary in order to prevent the motor from accelerating. This is done by means of either hand or automatic regulation. Continuous-current motors, however, are generally shunt-wound, and are connected in parallel with constant-potential mains.

Necessity for rigidly coupling series-connected motors.

Since the resistance of the armature of a motor is generally very small, being, say, but the fraction of an ohm, when such motors are connected across constant-potential mains, if the driving current should be turned on while the motor is at rest, there would necessarily be an inrush of current into the armature, that would, in all probability, injure the machine; for, although the armature would immediately begin to race; *i.e.*, run at a high speed, and endeavor to cut off the excessive current by rapidly developing a C.E.M.F., yet before this could be done, the excessive torque would possibly seriously damage the machine. Consequently, it is necessary, before starting a motor from a state of rest, to insert a resistance, called a starting resistance, into the armature circuit. This has the effect of decreasing the amount of current that first enters the motor, and so permits the motor to gradually come up to speed. As soon as this is accomplished, and the proper C.E.M.F. developed, the starting resistance is gradually cut out or removed from the armature circuit. A starting resistance is necessary both in the case of series-wound motors and shunt-wound motors. It is, however, more necessary in shunt-wound motors, because in series-wound motors the resistance of the field coils stops off considerable of

Necessity for use of a starting resistance in motors.

Necessity for use of starting resistance in both shunt and series-wound motors.

the current. Moreover, the inductance of the field coils, under the sudden tendency to increase the current strength, acts as an impediment to the passage of a powerful current through the armature.

Starting resistance.

In the form of starting resistance or rheostat, shown in Fig. 240, a number of coils of galvanized iron wire are mounted in a fireproof frame, and are connected in series with one another in the manner shown at the right-hand side of the figure. By means of the movements of a switch handle, shown at the top of the figure, over the contact points to which the coils are connected, either a part or all of the coils can be introduced into, or cut out from, the circuit of the armature. Since the coils of a rheostat are intended to carry a current for but the short time required to permit the motor armature to come up to speed, rheostats should never, unless specially constructed for such purpose, be permitted to remain any length of time on the circuit, since, otherwise, the coils may be burned out.

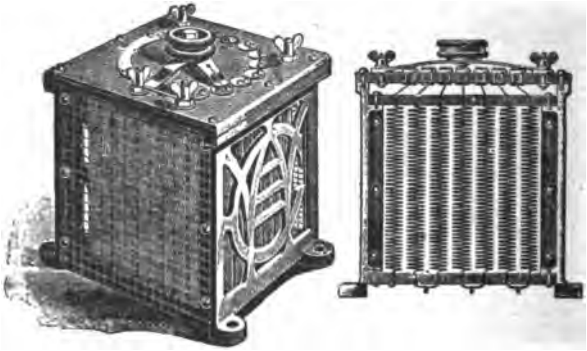


FIG. 240.—Starting Resistance or Rheostat for Electric Motor.

Liability of coils to burn out.

The direction of rotation of a motor can be reversed by changing the direction of the magnetic flux either in the field magnets or in the armature coils, as may be done by changing the direction of the current through either of these circuits. The reversal of the armature terminals required to change the direction of rotation is generally effected by means of a suitably arranged switch. Great care, however, must be exercised in reversing a motor, since the armature, while still rotating, will be developing an E.M.F., which will be no longer the C.E.M.F. of the current the armature is receiving, but will be similarly directed, so that a very great current strength tends to flow through the armature. Therefore, the use of a rheostat or resistance is even more necessary in reversing a motor than it is in starting a motor from a state of rest. Where electric motors require to be frequently reversed, they are generally series-wound, so that the resistance and inductance of the field magnet coils tend to prevent this excessive rush of current. Street-car motors, which are generally series-wound, sometimes employ a rheostat consisting of a number of separate wire resistances, so placed as to be readily inserted into or removed from the circuit of the armature by the movements of a suitably placed switch-handle.

How to reverse direction of rotation of electric motors.

Danger of suddenly reversing direction of rotation of motor without the use of a rheostat

Where it is necessary that the motor shall exert a constant pull or torque on its shaft at variable speeds, as in the case of electric elevators, electric cranes, or hoisting apparatus generally, some means must be employed for readily varying the speed. This can be done either by introducing resistances into the armature circuit of a shunt-wound motor, or by suitably varying the connections of the field coils on a series-wound motor. For example, the resistance r_1, Fig. 241, is inserted in series in the armature

Some methods employed for varying speed of motors.

r, as shown. The amount of this resistance in the circuit is varied by the movements of the switch-handle, represented in the figure by a horizontally placed switch arm, moving along different contact points connected with the resistance coils in the position shown in the figure, nearly all the resistance being in the circuit, while when the arm is moved toward the point of connection of the armature, more and more of the resistance is cut out of the circuit.

In series-wound motors, the necessary variations in speed are obtained either by varying the amount of current that passes through the field magnet coils, or by varying either the number or the connection of the coils on the field magnets, and thus varying the amount of the magnetic flux that passes through the armature. This method is shown at the right-hand side of Fig. 241, where the switch-handle *s*, placed in connection with the contact point *a*, permits all the current flowing through the armature to pass through the field coils 1, 2, 3, 4 and 5, but when moved toward the right-hand side, to cut out successively the different coils. Generally, however, the separate coils of the field magnets are so arranged that, in addition to varying the current

Speed regulation by varying field magnet coils.

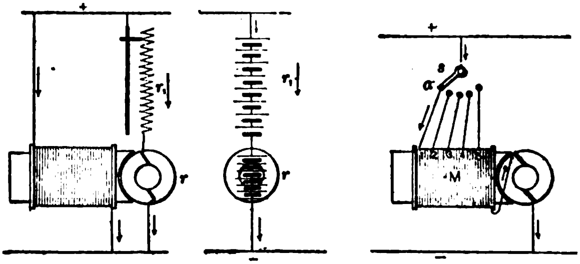


FIG. 241.—Some Methods Employed for the Regulation of Shunt and Series-wound Motors.

strength passing, the coils may be cut out or in the circuit, or the separate coils connected in series or in parallel with one another, as shown in Fig. 242, where a form of series-wound street-car motor is provided with three separate coils on each core of the field magnets. By the movements of a switch, each of the three sets of coils may be grouped, as shown at the right-hand side of the figure, either as at 1, where each set of three coils is connected in series; or at 2, where one of the coils in each set has been cut out of the circuit; or at 3, 4, and 5, where the coils are variously connected, either in series-multiple, or in multiple groups.

Field coils for varying speed.

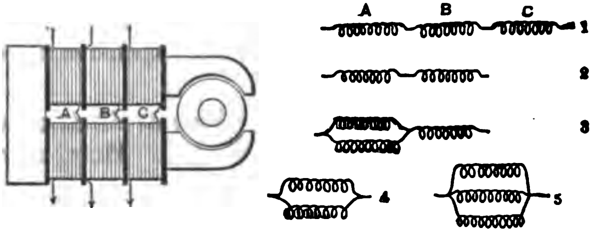


FIG. 242.—Method for Varying the Connection of Field Coils on Motor for Varying Speed.

The losses which occur in the electric motor are, in general, similar to those that occur in dynamos and generators. Such losses, therefore, are those that arise from mechanical frictions; that occur either at the bearings or brushes; or frictions due to air churning; or those that arise from magnetic frictions, that are due to hysteretical losses that occur by reason of the expenditure of energy required to reverse the magnetism in the masses of iron in the motor; or they are electric losses; viz., losses due to the setting up of eddy or parasitical currents in the masses of metal in the motor.

Character of losses in electric motors.

Slow-speed electric motors.

For many purposes it is desirable to obtain motors that, when running at a comparatively slow speed, will produce the necessary C.E.M.F. required to operate them when they are performing their regular work. Such slow-speed motors will generally have smaller frictional losses, on account of their slow speeds. For the same reason, the hysteretical and eddy current losses will also be smaller than in high-speed machines. But, while slow-speed motors possess the advantages above referred to, yet their output is necessarily less than that of high-speed motors, so that the decrease in their speed means the employment of heavier and more expensive motors.

General Electric Company's slow-speed motor.

A slow-speed motor, of the General Electric Company's type, is shown in Fig. 243. Here, as will be noticed, the bearings are supported by end-shields, which protect the armature and field windings. This motor is designed to operate equally well in an erect, an inverted, or semi-inverted position, so that it can

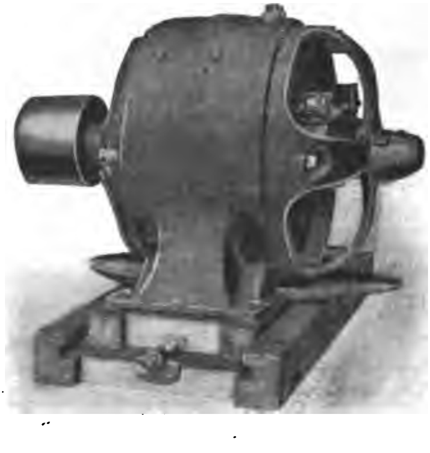


FIG. 243.—Slow-speed Motor of the General Electric Company's Type.

be placed on the floor, on the ceiling, or on a wall. Although the motor shown here is provided with a pulley, so as to be capable of connection by belting to the machine to be driven, yet these motors are constructed so as to be directly coupled to the shaft of the machine the motor is intended to drive.

Armature of slow-speed electric motor.

The completed armature of the above motor is shown in Fig. 244, at the upper part of the figure.

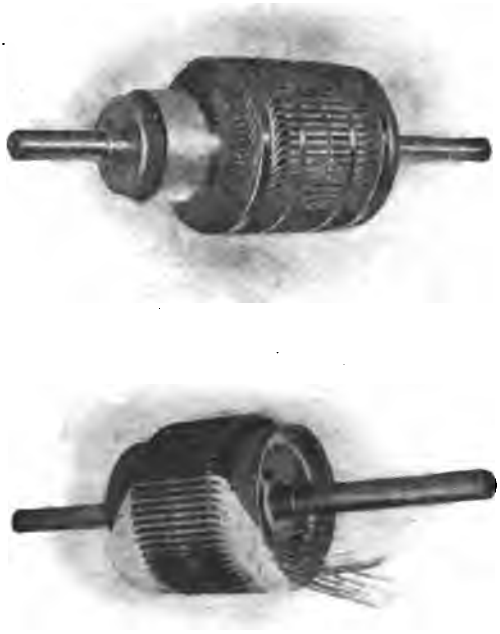


Fig. 244.—Completed and Partially Completed Armatures for Slow-speed Motor of Fig. 172.

Its core is laminated, being built up of a number of laminations of soft steel, so as to prevent losses from the formation of eddy currents. As in the armatures of generators, this armature is provided with air ducts, so as to permit efficient ventilation. It will be noticed that the armature is of the toothed core type, the windings or coils being inserted in the spaces between contiguous teeth, as shown at the lower part of figure. Carbon brushes are employed in this machine, as, indeed, is generally the case in electric motors, since such brushes may be so placed on the commutator segments as to permit the machine to readily run in either direction without shifting the brushes. Wherever the motor is exposed to flying particles of dust, perforated covers are placed over it. In some cases these covers are made practically air-tight.

Where the speed of the motor is too great to permit it to be directly coupled to the shafting of the machine to be driven, suitable gear wheels are employed for reducing the speed. Such a reducing set is shown in Fig. 245. Here one of the toothed wheels, called the gear, is connected directly to the motor shaft, while the other toothed wheel, called the pinion, is connected directly to the driving shaft

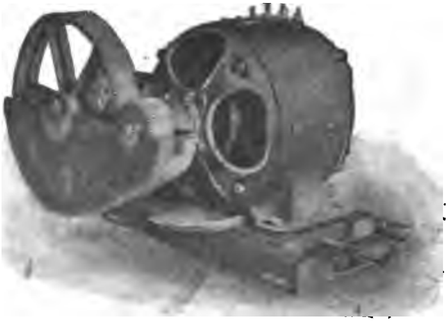


FIG. 245.—Reduction Gear for Electric Motor.

Reduction gear for motor.

of the machine it is tended to operate. The reduction will, of course, be proportional to the number of teeth in the gear divided into the number of teeth in the pinion.

Motor-driven punching tool.

Fig. 246 represents a form of General Electric Company's continuous-current electric motor directly connected with a 16-inch lathe. This is a ¾ horse-power motor. The reduction gear is clearly represented in the figure.

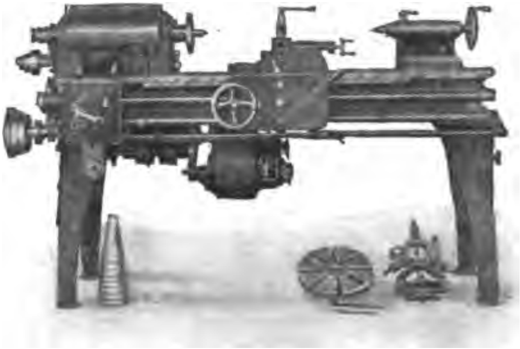


FIG. 246.—General Electric Company's 3-4 Horse-power Continuous-current Motor Directly Connected to a 16-inch Lathe.

Belt tightener for motor.

Where electric motors are not directly connected to the shaft, and, consequently, where belting is necessary, means are provided for tightening the belt. This tightening is effected generally by means of a screw, which slides the motor over a bed-plate provided for this purpose. Such a tightening screw is shown in the motor of Fig. 243. Sometimes the special device called a belt tightener, shown in Fig. 247, is employed. Here the ordinary pulley end-head and bearing of the motor are replaced by a tightener-head and bearing, such as shown in the

Special form of belt-tightener.

figure. The manner in which the belt is passed round the smaller pulley, in order to obtain reduced speed and rotation in two different directions, is shown in the figure. The use of such a tightener permits the diameter of the driving belt to be suitably decreased.

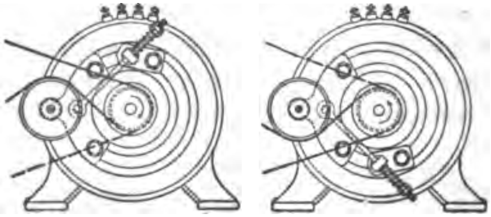


FIG. 247.—Special Form of Belt-tightener for Electric Motors.

A slow-speed, bipolar motor, of the Crocker-Wheeler type, is shown in Fig. 248. The cores of the field coils are formed of drop-forged masses of wrought-iron. In order to ensure a good magnetic joint between the cores and the cast-iron bed-plate on which the cores rest, the cores are inserted in

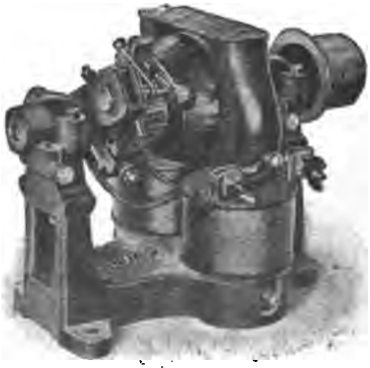


FIG. 248.—Crocker-Wheeler Slow-speed Bipolar Electric Motor.

Crocker-Wheeler slow-speed bipolar motor.

holes that are bored in the bed-plate to a depth sufficient to make the area of contact with the cast-iron twice the cross section of the field cores. This is necessary, owing to the fact that the magnetic permeability of cast-iron, *i.e.*, its conductibility for lines of magnetic force, is only half as great as that of wrought-iron.

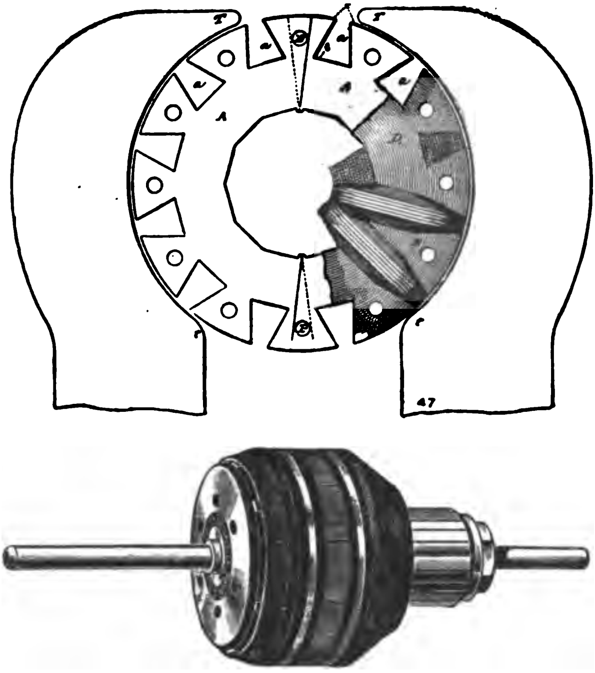


Fig. 249.—Armature of Crocker-Wheeler Bipolar Slow-speed Motor.

The armature of this motor is of the toothed core type, and is provided with slots, shaped as shown at *a*, *a*, *a*, etc., in Fig. 249. This shape possesses the advantage of leaving the armature teeth wider at the surface of the armature core. The armature coils are placed, as shown, in the spaces between

Armature of Crocker-Wheeler motor.

the teeth. The appearance of a completed armature, when mounted on its shaft and provided with a commutator, is shown at the lower part of the figure. Carbon brushes are employed as in practically all motors. The bearings of the machine are of the self-aligning and self-oiling type, oil being mechanically poured over the bearings by a process similar to that described in the case of the self-oiling bearings of generators.

Self-oiling type.

CHAPTER XXXI

SOME APPLICATIONS OF CONTINUOUS-CURRENT MOTORS

"It is the ease of control of an electric motor, its handiness, convenience, and the flexibility of the wire or wires which supply it, that make the electric subdivision of power so valuable an adjunct in manufactories."—DR. A. E. KENNELLY

Economy of separate motor drive of machinery.

THE continuous-current motor is applied to a great variety of work in driving machines of different types. In some cases, a single, large motor is employed to drive the main line of shafting in one large room, or on one floor of a large factory. In this case, the various machines in the room, or on the floor, are driven from the main shaft by means of belting and counter-shafting. In other cases, each machine is driven by directly connecting the motor to the shaft of the driven machine, as already shown in connection with some of the motors represented in the preceding chapter. The electric motor has been applied to drive a great number of machines of different types, and the applications of this character are rapidly increasing in number. In addition to the many advantages already pointed out that can be derived from the use of electric motors, especially direct-connected motors, there is to be added the very marked saving effected where machines are directly driven from electric motors. It has been shown that, in many cases, where long lines of shafting and counter-shafting are employed for driving a great number of separate machines, the energy uselessly expended in belt and shafting frictions bears a very large proportion to the entire energy required to drive the mill.

How to start a shunt-wound motor.

Before describing some of these applications, it will be well to discuss the steps that are generally taken in order to start a motor from a state of rest. In the case of a shunt-motor, this is generally accomplished in a manner that will be better understood from an examination of Fig. 250. Here the shunt-wound motor shown is connected with a pair of constant-potential mains through a cut-out, and, in this case, also through a double-pole quick-break switch, Q, to the starting box. The switch Q being closed, and the arm S drawn to the right, as indi-

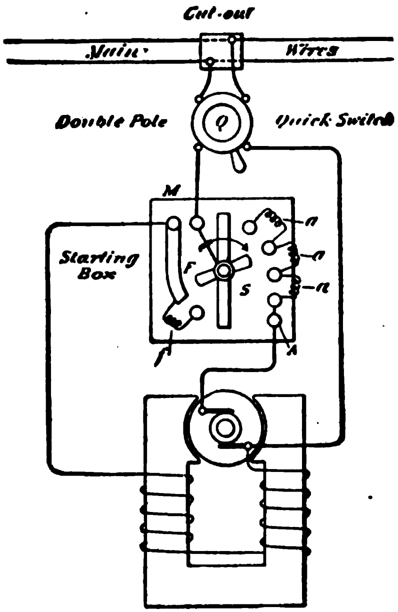


FIG. 250.—Diagram of Connection of Shunt-wound Motor on Constant-potential Mains.

cated by the circular arrow, contact through the strip F enables the field of the motor to be first brought into the circuit. When its magnetism has reached its full strength, which will generally require a few seconds, then the further movement of the switch Q closes the armature circuit through the resistance of all the coils *a, a, a.* By thus doing, the armature resistance is increased, so that the rush of current from the mains through the armature is prevented. The motor is now started, and as its speed increases, the C.E.M.F. it develops increases, thus permitting the arm S to be turned still further in the direction of the arrow. An examination of the figure will show that this movement will successively cut out the resistance coils *a, a, a,* until the motor is finally connected with the circuit, and is running at its full speed. These movements of the arm S must be sufficiently slow to permit the motor to acquire its speed and develop the C.E.M.F. before all the resistances are removed.

How to start a series-wound motor.

In starting a series-wound motor, the difficulties are less marked, since, as already stated, the resistance and self-induction of the machine tend to greatly retard the rush of current. Here, however, the resistance coils *a, a, a,* Fig. 251, are used. The connection is such that, when the motor is started, the circuit of the armature and field of the machine are in series with the resistance coils of the rheostat. Series-wound motors, when placed on constant-potential circuits, not having a constant strength of their field, do not tend to run, like shunt motors, at a constant speed, but are apt to race, when their load is suddenly removed.

We will now examine the application of a shunt-wound motor of the Lundell type to driving the

Starting of shunt-wound motor.

bellows which supplies a church organ with air. This is a character of work that requires close regulation on the part of the motor, so that it is necessary, in order to ensure efficient service, that the speed of the motor be maintained within very close limits. All the organist has to do is to move a starting switch in one direction. This sets the motor in operation, and supplies the bellows with the air required for the organ. Where many of the stops are open, and a large supply of air is necessary, the motor, if properly governed, rapidly speeds up and maintains the supply; while, on the contrary, if only a few of the stops are open, and but a small air supply is needed, the speed is decreased and the bellows is not overblown. Unless both of these requirements are met, the operation of the organ will necessarily be unsatisfactory. By the use of a suitable regulator, however, no matter what demand, within certain limits, is made on the bellows, a constant air pressure and a practically constantly filled bellows are ensured.

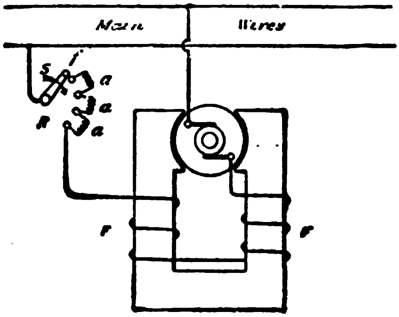


Fig. 251.—Connection of Series-wound Motor to Constant-potential Mains.

Advantages of a motor-driven bellows for church organs.

The motor once started, its speed is taken care of by the regulator before referred to. The lever arm of this regulator is connected by means of a flexible cord to the lever of the bellows, as is better shown in Fig. 252. The point of attachment of this cord must be such that the proper amount of movement is left between a full and empty bellows to permit the lever arm to move free of the points of contact in the resistance coils of the regulator.

Connection of lever arm of regulator with arm of bellows.

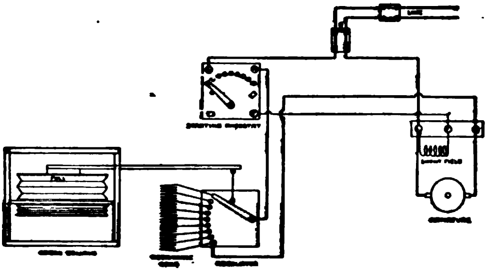


FIG. 252.—Connection for Motor Drive of Bellows for Church Organ.

Examining in detail the working diagram of this motor, we notice that the shunt-wound driving motor is connected across a pair of constant-potential mains, marked "line" in the figure. A safety fuse is placed in each main, and a switch provided to cut off the current from the building when so desired. The resistance coils of the regulator are placed, as shown, in series with the armature.

The necessity for providing fresh air in assembly, sleeping and working rooms, is well recognized. Where no better plan is possible, a fairly good system of ventilation can be obtained by intelligently opening windows; but in all places where electric current is available, as is now the case in nearly all densely populated neighborhoods, this can be much better done either by means of exhausting or ventilating fans, or air blowers, operated by means of

Application of motor-driven exhaust fans and blowers for ventilating rooms, etc.

electric motors. The ease with which such electric motors can be regulated as to speed, and can be either stopped or started, renders them especially applicable for this purpose.

Motor-driven exhaust fan.

A motor of the Lundell type, connected with a small exhausting fan, is shown in Fig. 253. This motor is mounted by means of brackets attached to a board, so cut as to fit the top or bottom of a window. A small wall switch, placed in a convenient position, permits the motor to be started and its speed to be readily controlled. Fans of this character are employed for removing air from rooms, offices, churches, hospitals, hotels, asylums, toilet rooms, and other similar localities. These motors are readily operated wherever incandescent lighting mains are accessible.

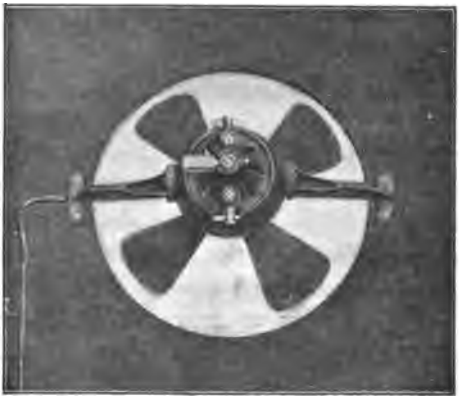


FIG. 253.—Motor Directly Connected to Small Exhaust Fan.

An enclosed, sextipolar, slow-speed motor, of the Lundell type, suitable for direct connection to ventilating fans and blowers, is shown in Fig. 254.

Here one of the covers has been removed, so as to show a part of the motor. The armature is well laminated, and the separate commutator segments insulated by sheets of mica. Radial carbon brushes are employed on the commutator. The direct connection of a motor of this type, with a blower, is shown in Fig. 255.

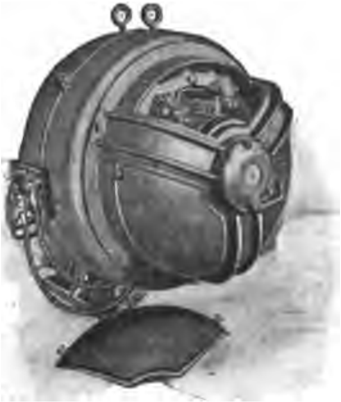


FIG. 254.—Lundell Type Motor. A sextipolar motor of the slow-speed type.

Slow-speed sextipolar Lundell motor.

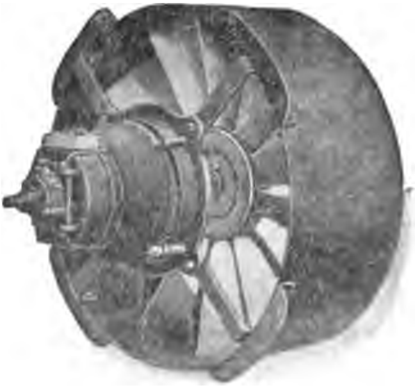


FIG. 255.—Motor Directly Connected to Blower.

Crocker-Wheeler sextipolar motor.

A Crocker-Wheeler, six-pole, shunt-wound motor, with its pulley removed, is represented in Fig. 256, as it appears from the commutator end of the machine. The magnet frame is made of cast-iron, and is jointed in one place, where it is split horizontally, so as to render it easy to assemble the various parts of the motor. The magnet frame is bolted, as shown, to a cast-iron bed-plate, and the field poles are formed of steel, that is cast-welded into the magnet frame. The field coils are wound with well-insulated, cylindrical bobbins.

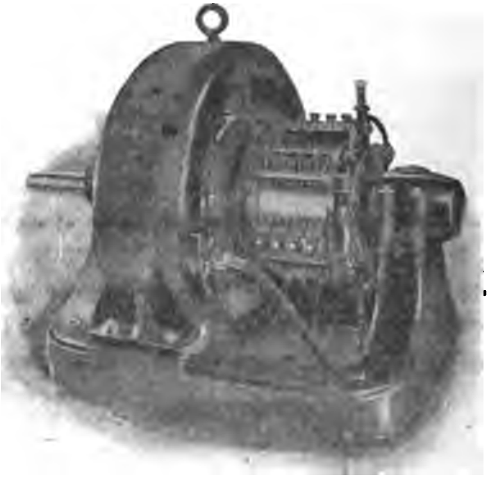


FIG. 256.—Shunt-wound Sextipolar Electric Motor.

Motor installation at United States Mint, Philadelphia.

The ability of a properly designed, continuous-current motor to satisfactorily perform the various operations required in coinage, has been demonstrated by the installation of electric motors in the United States Mint, at Philadelphia. Here some 108 separate electric motors, mainly of the Crocker-Wheeler type, aggregating some 1,000

ELECTRIC TRAVELING STAIRWAY IN A DEPARTMENT STORE

An escalator, operated by an electric motor, in a department store. Moving stairways, such as this, consist of endless belts, upon which one may stand or walk and be carried upstairs

horse-power, have already been installed. The motors vary in size from 1-6 of a horse-power to 50 horse-power. Practically all the machines in this building are driven by individual motors, which, as a rule, are specially designed for geared connections with the machines they are intended to drive.

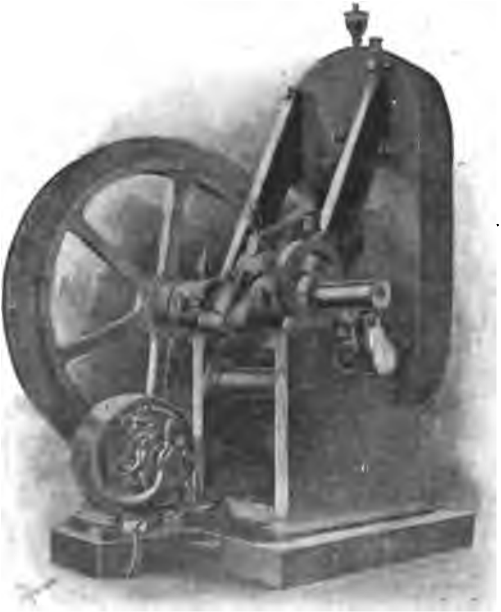


FIG. 257.—Electric Motor-driven Milling Machine, at the United States Mint, Philadelphia.

Brief description of processes employed at United States Mint

As is well known, on account of the softness both of gold and silver, it is necessary, when these metals are employed for coinage, to alloy them with various other metals. In order to ensure absolute uniformity in the amount of gold and silver in the United States coinage, the metals are first subjected to a process of electrolytic refining, by means of current supplied by a specially designed dynamo. By the employment of electrolytic refining, a degree of purity is reached as great as 999.9 parts in 1,000. After this practically pure metal has been obtained, it is alloyed with the proper proportion of other metals, in order to produce the United States standard gold and silver coins. This alloy is cast into suitable ingots, which are then submitted to various processes of cutting, rolling, cutting out blanks, forming a milled edge on the blanks, and finally coining. All these processes are carried out by means of electric motor-driven devices.

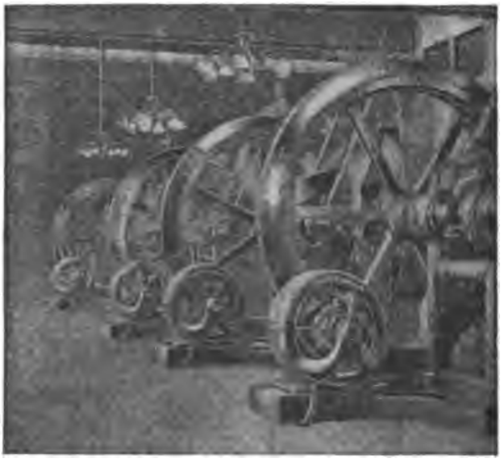


Fig. 258.—Group of Motor-driven Stamping Machines, in the United States Mint, at Philadelphia.

Some motor-driven tools.

It will suffice here to call attention to only a few of such machines, as, for example, the milling machine shown in Fig. 257, to the group of electrically driven stamping machines shown in Fig. 258, and to the motor-driven stamping press shown in Fig. 259.

Attention is called, in the electric motors represented in some of the preceding figures, to the marked discrepancy between the size of the driving motors and the size of the driven machines. It seems, at first sight, that it should be manifestly impossible for large machines to be driven by such apparently puny prime movers, but the amount of energy that can be obtained from a compact, well-designed and properly constructed electric motor of the modern type is exceedingly great. Indeed, this constitutes another of the many advantages of the electric motor, and is only another consideration which may

The smaller driving the larger.

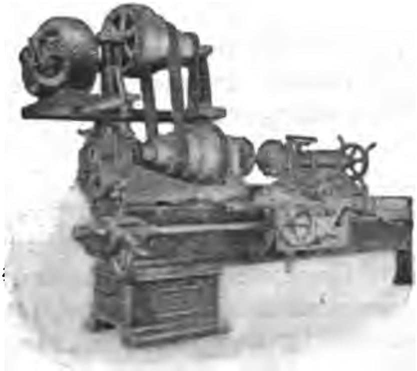


FIG. 259.—Electric Motor-driven Stamping Press, in the United States Mint, Philadelphia.

be added to those already mentioned as to why it is that so great an increase has been witnessed during the last two decades in the use of the electric drive of machinery of all kinds, instead of the old form of steam drive. Great as has been the growth within late years, the next few decades will, probably, see even a still more rapid growth. It must not be forgotten, however, that it is not here intended to convey the idea that such growth will result from improvements in the efficiency of electric motors; for, as we have seen, these have already reached an

Direction of probable future improvements in electric motors.

efficiency, in large sizes, of from 90 to 95 per cent, so that the possible improvement in this direction is necessarily limited to, say, some 10 per cent or 5 per cent. The improvements will, probably, be in the direction of obtaining even still better regulation, thus permitting the motors to be stopped, started, or reversed, and to be able to run at varying speeds. Indeed, even if such improvements are not made, the electric motors, as they exist at present, will, there is every reason to believe, greatly increase in the number and character of their applications.

General Electric Company's electrically driven machine shops at Schenectady, N.Y.

In addition to the installation in the United States Mint, another instance of an electrically driven manufacturing plant, that may be briefly discussed here, is that of the General Electric Company's shops at Schenectady, N. Y. Here, practically all the machinery is driven by means of some 3,000 horse-power of electric energy, that is transmitted to the works from Mechanicsville, some eighteen miles distant. All the large tools in the shop are driven by separate or independent motors. Travelling cranes, electrically driven and operated, carry electrically driven tools to heavy pieces of work, instead of carrying the work to the tools, electric hoists picking up the various tools with wonderful ease. Other instances of the employment of electric power for manufacturing purposes might be mentioned here; for example, as much as 5,000 horse-power is employed in the manufacturing plant of the Deering Harvester Company, at Chicago, Ill.

In the greater part of the United States, during some of the months of the year, the high temperature of the air, combined with the presence of an unusual amount of water vapor in the air, often renders it difficult to ensure comfortable human existence, especially in close offices, or rooms in the densely populated parts of the city. The use of hand-moved fans to stir the air, and thus produce a lower temperature of the body through an increase in the evaporation of the moisture from its surface, is only possible in the comparatively rare cases of those who have time for such use. Fortunately, however, the electric motor wonderfully adapts itself to work of this kind, and a great increase has been noticed in the number of motor-driven fans.

Adaptability of electric motor for driving small fans.

Fan motors are generally constructed so as to be operated on the constant-potential circuits employed in supplying incandescent lamps with their working current. Although motors have been devised for use on arc light circuits, yet such use is not advisable, by reason of liability to exposure to dangerous pressures unless great care is taken. It is a fortunate circumstance that the time when the least load is placed on the central station comes at such time during the twenty-four hours of the day when the greatest number of fans are apt to be in use. This permits the average load of the central station to be materially increased, so that the central station is able to offer inducements to its customers, either in the form of rebates, or of smaller charges for the current supplied during the hours of light load. It is not remarkable, therefore, although it may be a surprise to some, that, within the past few years, an enormous increase has taken place in the amount of electric energy that is required for the driving of fan motors. In the Census Bulletin for the 12th Census of the United States, published at Washington, D. C., August 25,

Why use of fan motors has greatly increased.

1902, the following very interesting remarks are made concerning this particular application of the electric motor:

United States Census Report on the increase in the use of small electrically driven fans.

"The statistics as to electric fan motors are especially interesting, as illustrative of the development of a distinctively American industry that has grown up during the last census period. The records show that in the early eighties, Dr. S. S. Wheeler, an electrical engineer, of New York, hit upon the idea of connecting a 'screw propeller' fan to a small motor which he had been developing, to be operated from primary batteries. At that time there were few circuits available for incandescent lighting, and some of the fans were placed upon the series arc-lighting circuits, a combination that was at once dangerous and economically undesirable. Little advance was made until in 1888, when a successful attempt was made to introduce such fans upon the low-potential, constant-current circuits for incandescent lighting, each taking the place of a lamp. Battery current had been so expensive as to limit the use of this ventilating device, but as soon as central-station current was available, the fan became popular, and, about 1890, the industry, as such, took definite shape. A couple of years later the well-known electric ceiling fan was introduced, and since that time the production of desk, bracket, ceiling, rotating, and other fans, for domestic and foreign trade, has grown by leaps and bounds, and American fan motors are now supplied to every quarter of the globe.

Some types of fan motors.

"One improvement consisted in putting a guard around the fan to protect unwary fingers; another, in enclosing the motor by the field magnets and frames so that none of the working parts were exposed. Fans to work on trunnions, to hang in chains, or to swivel, so as to throw the breeze evenly all around a large area, are among the modifications; while an ingenious variety has resistance heating strips so arranged in front of the fan blades that in winter warm air is projected from them. The use of ordinary resistances in the base in connection with the fans enables the speed to be closely regulated, so that the velocity of the breeze is under the control of the user. The popularity of these fans has been so great that during the census year the supply was far short of the demand. In the aggregate the consumption of current by this apparatus is considerable, and it will be noted that the capacity of the 98,577 reported during 1899-1900 was 12,766 horse-power. The steady operation of these through the summer months would make a notable consumption of current, to some extent replacing that due to incandescent lamps. In fact, the average daily use of an incandescent lamp is barely an hour or two, but it is by no means unusual for a fan motor to be started at 8 or 9 A.M. and to run steadily through the summer day until 5 or 6 P.M. As a fan consumes on an average about the same current as an incandescent lamp, the fans that have been put on the circuits during the last ten years do much to equalize the winter and summer 'load' on central stations and isolated plants."

Some improvements in fan motors.

Extent of load of central station from fan motors.

Forms of fan motors, suitable for use on constant-potential mains of from 115 to 230 volts, are shown in Fig. 260. These mains are provided with a small hand switch for starting and regulating the motor. In this manner three different speeds can be obtained; viz., 900, 1,200, and 1,600 revolutions per minute. The fan shown in the bottom figure on page 450 is mounted on a stand, in the usual way; that shown at the top of the figure is supported as shown on a bracket, where,

Fan motors with variable speeds.

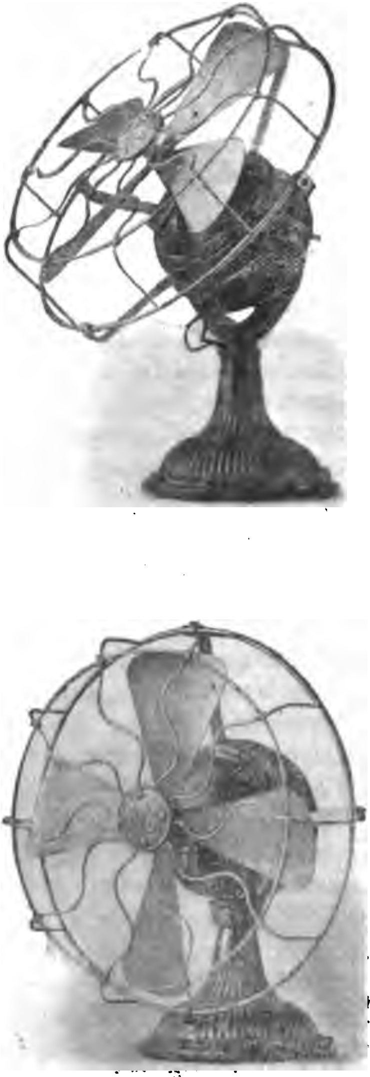


FIG. 260.—Fan Motors with Variable Speeds.

by means of a universal joint, the fan is permitted to be turned at any angle, so as to throw the air either toward or from certain parts of the room, as may be desired. This is often very desirable, since at times, especially when the body is unduly heated, it is both unpleasant and unsafe to permit a strong current of air from the fan to be thrown directly against the body; while, at other times, such air current is greatly to be desired.

Ceiling fan combined with groups of incandescent electric lamps.

In order to keep the air in large rooms in a gentle motion, fans of large size are employed. These are either supported on the tops of vertical posts, or, as is more usually the case, are suspended from the ceiling. In the latter case, in order to avoid unsightliness, the fan is frequently combined with a group of incandescent electric lamps. Such ceiling-suspended fans are especially applicable in restaurants, hotel corridors, department stores, and in other similar locations.

Some requirements for elevator motors.

Another important use of large electric motors is in the operation of elevators. For such purposes, a slow-speed motor must be employed, that is capable of running equally well in both directions without its diameter of commutation varying, and, consequently, without sparking at the brushes. The motor must be able to start at heavy loads, that is, when the car is filled with passengers. What is perhaps most difficult to ensure, is that the electric apparatus required in operating the motor must be capable of being used by people who are absolutely ignorant of even the elementary principles of electric science. In addition, the motor employed for driving the apparatus must not only be capable of operating in the small space that is generally devoted to the driving machinery of elevators, but must also be of such a nature as not to be readily injured by the dampness and dust common to such spaces. Notwithstanding all these difficult requirements, the operation of elevators by electric motors has been very successfully accomplished, and motors are rapidly coming into use for this purpose.

An electric motor of the Holtzer-Cabot Company's type, shown in Fig. 261, is much employed for the driving of elevators. Here, as seen in the figure, the motor is only partly enclosed. The field poles are of wrought iron, cast-welded in the form of pole shoes, which hold the field coils. These iron masses are thinner at their edges, thus per-

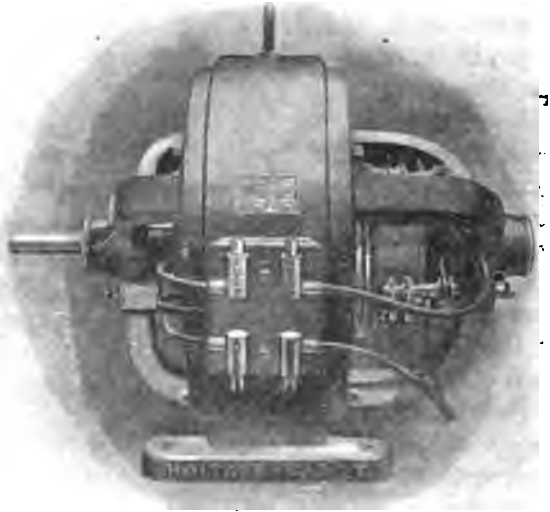


FIG. 261.—Holtzer-Cabot Motor for Driving Elevators.

Holtzer-Cabot Company's electric motor for driving elevators.

mitting the armature coils to leave the field near the poles through a region that gradually decreases in magnetic density, and, by aiding in fixing the diameter of commutation, avoid sparking. The armature core is thoroughly laminated. The machine is compound-wound, and has, in addition to the shunt winding, a heavy cumulative compound winding. The armature is wound with a proportionately great number of turns of wire, so that its resistance is fairly high. The motor is capable of running at various speeds, by means of resistances inserted into the field circuit, so that the latter is able to rapidly come from a state of rest up to full speed.

Some statistics of electric elevators.

So satisfactory has been the work of electric motor-driven elevators that, toward the close of 1901, there were some 3,000 separate elevators operated by direct-current motors, and some 300 by alternating-current motors, in the city of New York alone. In order to get some idea of the character of the work done in this direction, let us take the case of the elevators installed in Park Row Building, New York City, a 29-story structure. Here five elevators have been installed for carrying passengers as high as the 26th floor. To do this, the car requires to be raised through a vertical distance of 308 feet. The freight elevator, which runs from the basement to the 25th floor, raises its load through a vertical distance of nearly 424 feet.

Elevator at Washington monument.

Or take the case of the electric elevator in the Washington Monument, at Washington, D. C. This elevator replaced the steam-driven elevator formerly employed. The Washington Monument is some 555 feet high. During every week day, Electric elevator twice as rapid as steam.

this elevator lifts a load due to the weight of about 400 people. When the old steam elevator was running, this lifting was done at the velocity of about 50 feet per minute; now, with the electric elevator, this velocity is about 100 feet per minute, thus cutting down the time required for each service from approximately ten minutes to five minutes.

CHAPTER XXXII

EARLY HISTORY OF THE ELECTRIC STREET RAILWAY

"Since then on many a car you'll see
A broomstick as plain as plain can be;
On every stick there's a witch astride,—
The string you see to her leg is tied.
She will do a mischief if she can,
But the string is held by a careful man,
And whenever the evil-minded witch
Would cut some caper he gives a twitch.
As for the hag, you can't see her,
But hark! you can hear her black cat's purr,
And now and then as a car goes by,
You may catch a gleam of her wicked eye.
Often you've looked on a rushing train,
But just what moved it was not plain.
It couldn't be those wires above,
For they could neither push nor shove;
Where was the motor that made it go—
You couldn't guess, *but now you know.*"
—*The Broomstick Train:* Oliver Wendell Holmes

Stage coaches and omnibuses.

THERE are many people now living who can remember the time when the only means of going from one part of a city to another, other than by walking, was either by the clumsy horse-driven coaches or the omnibuses. Then, excepting those who could employ steam cars, people doing business in the city necessarily lived within the city limits, at comparatively short distances from their places of work.

Horse cars.

Then came the horse cars, drawn on tramways or iron tracks laid in the streets. This was a great improvement for those early times, and, quite naturally, caused an increase in the amount of travel, owing to the greater certainty of service and the decrease in the time required to reach distant parts of the city. The possible dwelling area of the city for the working classes was then increased, many being able to live at much greater distances from their places of work than was formerly possible.

Cable cars. Then came the great improvement in the cable cars, in which a heavy continuous cable was pulled, along with the cars holding on to it, through an underground conduit, suitable grips being provided which would enable the gripman to attach or detach the grip, so that his car could start or stop at will. Although this system of car propulsion was a great improvement over horse cars, yet its clumsiness and the stoppage of the entire line of cars when any accident happened to the cable, led to the invention of many devices for the purpose of propelling the cars by separate or individually operated motors. **Air-motors for cars.** Air motors were suggested for this purpose, in which the cars were driven by motors, operated either by air under great pressure in metallic cylinders placed under the car bodies, or even by liquefied air. None of these methods of propulsion, however, was satisfactory, and the clumsy, under-running cable, with its unmechanical appliances, continued in use.

Electric street cars. Finally, however, the electric propulsion of street cars came into use, and with its advent other systems were rapidly replaced. Now we have electrically driven street cars, each car being provided with a number of separate electric motors, operated by current generated at a distant power-house, and conveyed over a line of conductors either by means of an overhead or an underground wire. The current is taken from the trolley wire by means of a travelling contact wheel, attached to the trolley pole in a manner that is familiar to all; or it is taken off a conducting wire by means of an under-running trolley.

Electric traction *vs.* steam traction.

The system of electric traction by separate electrically driven motors is now so successful that it is rapidly becoming a dangerous rival for steam roads; for, the electric car is no longer limited to operation within city limits, but now extends from town to town, in many locations, paralleling existing steam roads.

Rapid transit and the growth of cities.

With the modern method of cheap and rapid electric transit, it has become possible for workers to live at comparatively great distances from the more densely built up portions of the city. Consequently, nearly all cities have gradually expanded in area, and with this expansion has occurred a marked unsettling of real estate values. There was originally a great increase in the value of the necessarily limited desirable tracts of land situated on the outskirts of large cities, and readily accessible by the old street-car systems, or the cable roads. Now, however, with the great extension of electrically driven trolley cars, when it is only a matter of an additional half hour or so, to be able to obtain the advantages of far better locations, the high prices formerly demanded for specially located outlying lots in a city have markedly decreased.

Element of the uncanny in many of the practical applications of electricity.

To those who are unfamiliar with the general principles of electricity and magnetism, some of the applications of these sciences to the economic arts often appear to possess an exceedingly uncanny element, so that the ignorant might almost be led to believe that they were living in a world of magicians and genii, instead of only very up-to-date and matter-of-fact people. Take, for example, the case of the electric propulsion of the street car that we are now considering. All that the public can actually see is what the motorman does, saving, of course, the occasional flashing that occurs at the trolley wheel, or between the car wheels and the ground. As soon as the motorman turns a handle connected with a metallic box at his left-hand side, the car is immediately propelled as though some unseen genie had taken it in his grasp and was hurrying with it along the streets. Where does the energy which drives the car come from? The trolley wire looks the same when the car is moving as it did before the car began to move. These difficulties, of course, at once disappear when the theory of the matter is understood.

Apparent mystery of electric propulsion.

It is an interesting fact that nearly all the old fairy stories appear to have been purposely framed so as to recite as possible only the most improbable, if, indeed, not impossible, things. Take, for example, the story of the prince who was in trouble to find horses to properly mount his army, and note the wonderful power his fairy godmother gave him of bringing a splendid horse, fully equipped and ready for work, up out of the ground whenever he stamped his foot—a horse for each stamp. Could anything apparently be more improbable than such a story? Could the intellect of man ever hope to be able, not only to render such a story true, but even to do vastly more than claimed by this old story? And yet the motorman of the modern street car can do all this, and even much more; for, when he taps on the ground, by turning the handle of the switch at his left-hand side, he brings up out of the ground not a single horse only, but, in the

Matter-of-fact Twentieth Century outranks the age of fairies and genii.

case of the modern street-car, equipped as it is with four separate electric motors, one attached to each driving wheel, as many as 150 horses, *i.e.* 150 electric horse-power. Moreover, these horses are better trained than any that are produced either in actuality to-day, or in the imagination of the old fairy story, for they can all be made to pull so nearly together that the loss or lack of efficiency is extremely small. Moreover, the electric horses called out of the ground at the tap of the motorman, when all their work is done, can be silently dismissed through the ground back to their stable; viz., to the power-house where the electric current is produced, and, moreover, when at their stalls in such house, can be better fed or nourished by the coal burned under the boilers of the central station, than can the more substantial horses be fed with the oats and hay necessary in such cases. Is not the reality, as it exists to-day in the case of the electric street railway, even more strange than in the case of the fairy story?

Electric horses *vs.* real horses.

Before entering into a description of the system of electric propulsion for street cars, it will be interesting to give a brief history of the early development of this branch of the electric arts.

The first three applications of the electric propulsion of cars were made between the years 1834 and 1840, in the United States, in Scotland, and in England, in the above-mentioned order.

Early workers in the line of electric street cars.

Thomas Davenport, the Vermont blacksmith already referred to, appears to have been the first to apply for a patent for an electric motor for the driving of street-cars. Davenport's first motor was constructed in 1834. In 1835, he had constructed

Thomas Davenport of Vermont

a small circular railway, at Springfield, Mass., on which he operated a motor-drawn car. His patent, entitled an "Application of magnetism and electro-magnetism to propelling machinery," was the first United States patent ever taken out for an electric motor. It is evident that the official examiner in the Department of Electricity, during these early days, was either an extremely liberal man, or else he regarded the motor of Davenport as an invention of great novelty, since he granted Davenport the following exceedingly broad claim: viz., "Applying magnetic and electro-magnetic power as a moving principle for machinery, or in any other substantially the same principle."

Robert Davidson of Scotland.

The Scottish inventor was Robert Davidson, who, in 1838, invented the electric motor which he applied for the driving of a small locomotive, as we have already mentioned.

Henry Pinkus of England.

The English invention was made in 1840, by Henry Pinkus, who took out a patent in England for a system of electric propulsion of cars, by means of current from voltaic apparatus placed in a central station or buried underground; or, as he stated in the specification of his English patent, by erecting a central station in which an electric battery or batteries are placed, or constructing wells or tanks, too deep in the ground to interfere with agricultural operations. Pinkus proposed to apply electric propulsion to carriages on ordinary roads (automobiles?), or on vessels afloat. There is, however, no evidence that he ever did anything more than theorize concerning this method of electric propulsion. Unlike the preceding inventors, he does not appear to have ever put his inventions into actual practice. He had, however, evidently given considerable study to the subject of the electric propulsion of cars, carriages and boats; for, as early as 1834, he had taken out a British patent for "An improved method or an apparatus for communicating, and transmitting, or extending motive power by means whereof carriages or wagons may be propelled on railways or common roads, and vessels may be propelled on canals." This invention relates to a pneumatic railway, in which magnetic attraction was to be employed for governing the air supplied to the motor.

An earlier invention of air-propelled cars and vessels.

In 1847, Moses G. Farmer constructed and exhibited an electro-magnetic locomotive, capable of drawing a car carrying two passengers.

Farmer.

In 1851, Page, in America, made a trial trip of an electric locomotive between Washington, D. C., and Bladensburg, on the Baltimore & Ohio Railroad, already referred to.

Page.

In 1879, George Green, in America, invented an electric motor somewhat similar to that of Farmer, but containing several important improvements. Green applied for a United States patent for this motor as early as 1879, but his application was placed in interference, and the patent to him did not issue until 1891. In 1879, Siemens & Halske, in Germany, constructed and operated an electric railway at the Industrial Exhibition of Berlin. The current required for driving the locomotive in this railway was obtained from a central station, the current required for the motors being taken, by means of a travelling contact or shoe, from a third rail placed between the two tracks.

Green.

Siemens & Halske.

But all the efforts of these inventors successfully to apply the electric motor to the operation of street

Why the early inventors failed.

railways failed, because the dynamo-electric machine had not yet been sufficiently developed to enable it to readily and cheaply supply the driving current. As we have already seen, it was not until Gramme greatly improved the dynamo, and it had become generally known that any good dynamo was capable also of acting as a motor, that the practical operation of electrically driven street cars became a possibility.

Interference suit, Edison *vs.* Field.

Without attempting to describe the many inventions that were made as soon as the facts, above referred to, became self-evident, it will suffice to call attention to an application made in the United States Patent Office by Edison, on June 5, 1880, for an electric railway. This application was placed in interference with a caveat filed in the Patent Office on May 21, 1879, by Stephen D. Field, and an application of Dr. Werner Siemens, of Germany. Siemens' application was subsequently thrown out of the office, and, after a long and tedious litigation, the United States Patent Office awarded the priority of invention to Field, and granted him a patent for the combination of an electric motor, operated by means of current from a stationary source of electricity conducted through the rails. Long before this award, however, a consolidation of the Field and Edison interests was effected, and a company, called the Electric Railway Company of the United States, was incorporated to exploit the patents of both inventors.

Field's patent on the electric railway.

The Electric Railway Company of the United States.

In 1881, Field constructed and operated a railroad at Stockbridge, Mass. In 1883, the Electric Railway Company of the United States constructed and operated a railway at the Chicago Railway Exposition. The electric locomotive employed for this work, called "The Judge," after Chief-Justice Field, of the United States Supreme Court, is shown in Fig. 262. On this railroad both generator and dynamo consisted of the same type of apparatus: viz., a shunt-wound dynamo of the Weston Company's manufacture. A central rail was employed for conveying the current to the motors, the tracks being used for the return circuit. In order to lessen the resistance of the tracks, the joints between successive rails were bridged or bonded by conductors consisting of pieces of stout copper wire.

"The Judge."

Electric railway at the Chicago Railway Exposition.

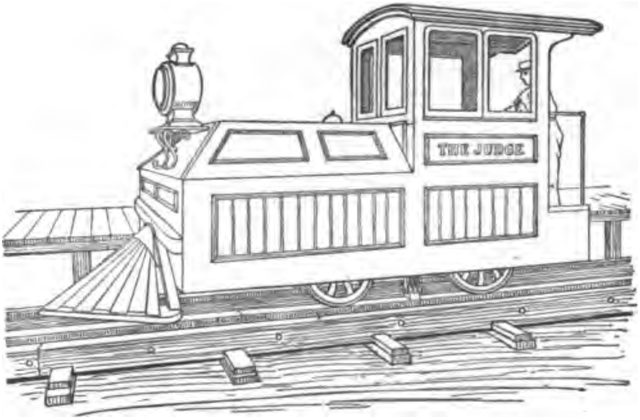


FIG. 262.—Field's Early Electric Locomotive—"The Judge."

In 1881, Edison built a railroad track, about half a mile in length, near his residence at Menlo Park, New Jersey, on which he operated a car by an electric locomotive, shown in Fig. 263. Here, as in the case of Field's locomotive, both generator and motor consisted of two dynamos of the same type, Edison employing for this purpose dynamos of his own construction. After these early railroads, many others were constructed, both in this country and abroad, until improvements in the art

Edison's electric railroad at Menlo Park, N. J.

had brought the system of electric railroad propulsion up to the highly developed condition that it is in to-day.

Rapid growth of electric street cars.

We have thus very briefly given a few only of the facts connected with the early history of the electric street railway. The growth of this system of car propulsion has been phenomenally rapid. There were no electric street railways in commercial operation prior to 1886. In 1890, out of the 789 street railway companies then doing business in the United States, 144 employed electric cars. Out of a total of 32,505 cars, 2,895 were electrically propelled.

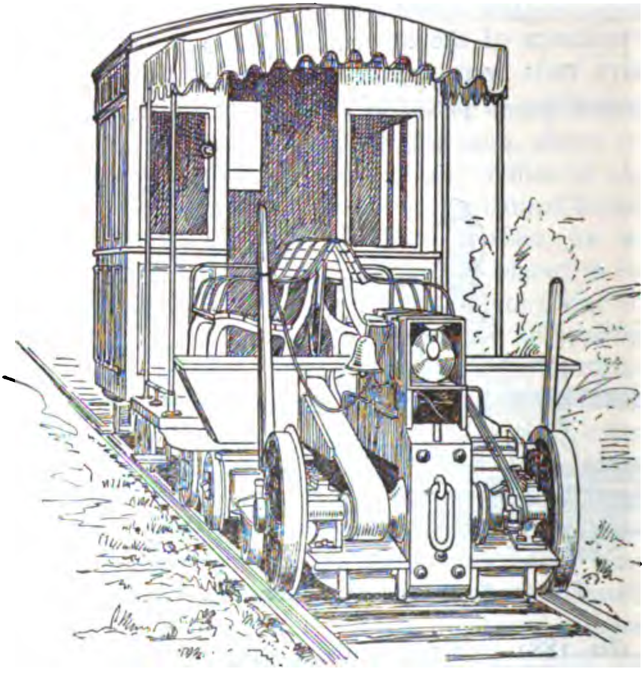


FIG. 263.—Edison's Early Electric Locomotive, employed on electric railroad at Menlo Park, New Jersey.

The electric cars, however, covered, proportionately, a greater extent of track per car, the electric cars running on some 1,262 miles of track out of the total 8,123 miles employed by both systems. In 1890, while the number of both horse cars and cable cars in actual service had markedly decreased, the electric cars showed a great gain. For example, the horse cars had decreased from a total of 22,408 to 1,489, cable cars from 5,089 to 4,250, while electric cars had increased to 50,658, and the total miles of track to 17,969.

Amount of capital invested in street railways.

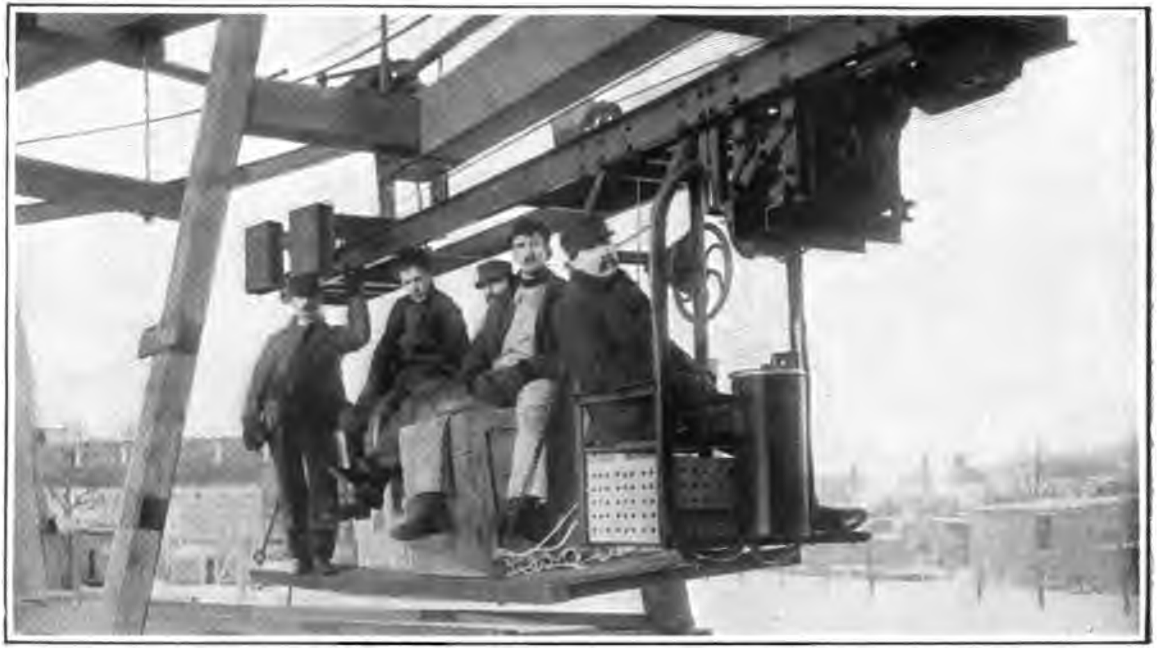
In 1890, the total capital and funded debt for all street-car roads was slightly over $363,000,000, while, in 1900, the total capital and funded debt for 871 railway systems, chiefly electric, was slightly over $1,800,000,000, or five times the figures of the previous decade. Nevertheless, on this vast capitalization, there was apparently an earning capacity of from 4 per cent to 5 per cent. The 12th Census of the United States gives the following interesting data concerning this matter:

Quotation from United States Report for 12th Census

"In the earlier days, such as those of 1890, a car with a pair of small motors of 15 horse-power each was well equipped, but it will be noticed that the average, per motor, in 1900, is apparently over 40 horse-power, while more motors were produced than the new cars would require if equipped with but 2 motors each. This discrepancy is explained not only by the large exports of electric-railway apparatus, but by the tendency to renew the old motors and increase steadily the capacity of the motors under the newer cars. Moreover, there was a notable extension of rural and elevated railway work, calling for heavier motors, and frequently involving the putting of 4 motors under each car, 1 on each axle. Not included in this report are 158 electric locomotives, valued at $288,071, nearly all for mining purposes, included in the report on locomotives by Mr. Edward H. Sanborn.

Enormous horse-power installed for electric car traction.

"No separate itemization has been made in the present report of the dynamos—*i.e.,* 'generators' built for street railway work, and no attempt has been made to keep separate the supplies required by this large industry. To differentiate between dynamos built for railway work and those built for other work is becoming daily more difficult, especially where all classes of service depend, as they now frequently do, upon the utilization of some distant water-power. The requirements of the industry are, however, enormous, and the data in hand show that in the ten years betwen 1890 and 1900, the railway power plants of the United States had installed, available for traction purposes, about 1,000,000-horse-power of dynamos to feed current to motor cars of a capacity of somewhat over 2,000,000-horse-power. In the same ratio, the 660,000-horse-power produced in 1899-1900, as shown by the present figures, would require about 330,000-horse-power dynamo capacity in the station plant, or a little less than half the dynamo production for that period, as shown by the table of dynamo manufacture. These figures appear reasonably consistent with the state of the electrical industry as gathered from observation of its evolution and tendencies."



TELPHER LINE HIGH ABOVE THE GROUND

A telpher is both an aerial trolley-car and an elevator. The car here shown is running on the overhead track seen curving to the left of the picture, and taking current from the wire seen a little above that. The men are on the "hoist." (See page 497)

CHAPTER XXXIII

THE ELECTRIC STREET RAILWAY

"During the past few years electric traction work has been passing through a transition period, outgrowing the restricted limits of city surface traffic and encroaching upon a class of work hitherto accomplished with the steam locomotive. The broadening of the electric traction field has necessitated considerable development in the motive power, and the transmission and collection of electrical energy."—*Notes on Modern Electric Railway Practice:* ALBERT H. ARMSTRONG

General method of operation of electric street cars.

IN the electric street railway as it exists to-day, the cars are propelled over a track laid down on the surface of the street. The motors are connected directly to the driving axles of the car, and take the current required to operate them either from an overhead conductor called a trolley wire, by means of a travelling conductor, called a trolley, or, from an underground conductor, by means of a travelling conductor, placed under the car body. Sometimes a metallic circuit is provided for the return of the current to the generators at the central power-house, where the driving current is produced, but generally, the track and ground, aided, as a rule, by return conductors, are employed.

Why greater electric driving power is required.

Within the last few years the size of street cars has greatly increased. This is especially the case, both in the interurban lines, or lines between neighboring cities, and in suburban lines, or lines at the outskirts of cities, where higher speeds and heavier traffic have necessitated longer car bodies. Consequently, more powerful motive power has been

Double-truck four-motor equipment.

required, both by reason of the increase in weight of the cars, and the increase in the speed at which they travel in the less crowded parts of the city. Moreover, in electric systems the stoppages are more frequent than in the case of steam roads, so that the ability to attain a high speed very soon after starting adds an additional need for a greater driving power. By reason of all these demands on the driving power, it is now very common to install four separate electric motors on each car truck, each motor being directly connected to a car axle, as shown in Fig. 264, which represents a double car-truck with an equipment of four separate electric motors, one of which is directly connected to each car axle.

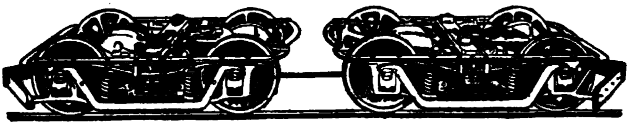


Fig. 264.—Double Electric Car Trucks, with Four-motor Equipment. Note here that a separate motor is provided for each car axle.

Car trucks and car bodies.

The body of the street car is supported on what is called a car truck. Sometimes a single truck is used, provided with two separate axles. Now, however, this is almost entirely replaced by two separate trucks, one at each end of the car. In such cases, the car is supported on a swivel centre on each truck. Sometimes, indeed, three trucks are employed, the centre truck being movable. This is specially applicable in the case of long, rapid-running cars. In such case the car body is supported on the centres of the end trucks, so as to be able to readily turn on them, the centre truck being carried between them.

A modern form of electric street car, with the car body mounted on a double truck, and provided with a 4-motor equipment, is shown in Fig. 265. This car is of the type in which the driving current is taken from an overhead trolley wire or conductor by means of the well-known trolley pole, and is one of the cars employed by the International Traction Company, at Buffalo, New York. The total weight of the car body, including the trucks and the four separate motors, is 44,400 lb. Each motor weighs 2,100 lb., so that some 8,400 lb. of the total weight comes from the motors alone. Although, as in the

Double-truck four-motor car.

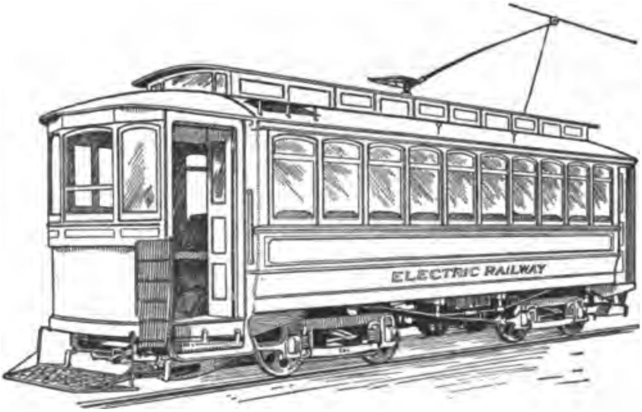


FIG. 265.—Electric Street Car with Four-motor Equipment. Note the positions of the well known trolley-pole, rope, and wire.

case of all locomotors, or travelling motors, it is desirable, for the purposes of economy, to reduce as far as possible the weight of the motor and car, yet, as is well known, a certain weight is necessary in order to obtain sufficient adhesion of the car to the track to readily permit the speed to rapidly run up on starting over slippery rails covered with ice or snow. Within reasonable limits, therefore, an increase in the weight of a car, so far from being objectionable, is necessary for proper operation.

Certain weight of car necessary for successful operation.

Two large *vs.* four small motors.

Sometimes, instead of employing four separate motors, two larger motors are used, having the same aggregate horse-power. An advantage is thus gained in a smaller aggregate weight; *i.e.*, 7,330 lb. for the two motors, as against the 8,400 lb. for the four motors, and also a slight economy in the driving power, the efficiency of the two motors being 87 per cent as against 84 per cent in the case of the four motors. But notwithstanding these advantages, the greater advantage of enabling the car to rapidly gain its full speed, after stoppages, more than compensates for the small loss of power. Moreover, the four separate motors, owing to the fact of their greater radiating surface, tend to heat much less than two motors. The total horse-power of the four-motor equipment represented in the preceding figures is 150 horse-power.

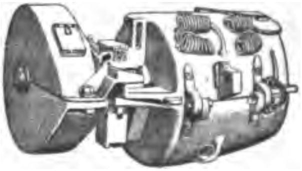


Fig. 266.—Railway Motor and Gear Case, Westinghouse Company's Type.

Westinghouse railway electric motor.

A street-car motor is always series-wound, and is generally of the quadripolar type, that is, employs four separate magnet poles for its field. Since the electric motor is hung beneath the car body, where a comparatively small space is allotted it, the field magnets are made as short as possible, and have their cores formed of steel in place of cast-iron. Car motors are necessarily exposed to the dust and mud from the street. They are therefore provided with a dust and mud proof case, as shown in the case of a car motor of the Westinghouse Company's type represented in Fig. 266. Here the motor is contained within the case represented at the right-hand side of the figure, the smaller case at the left-hand side being the gear case. The same motor, with a part of its field lowered so as to permit the removal of the armature, is shown in Fig. 267. Here the pinion, the name given to the toothed wheel connected directly with the armature shaft, is seen in the lower part of the figure, while the gear that engages with the pinion, when the motor is in a position for operating, is seen in the upper part of the figure. A portion of each of the two field-magnet poles is seen in the lower part of the figure, together with the commutator, which, in this case, contains more than 100 separate segments, and is provided with carbon brushes not here shown.

Railway motor with one-half of field removed.

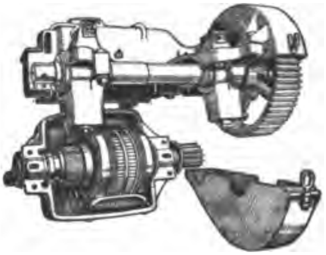


FIG. 267.—Motor of Figure 266, with one-half of field lowered for removal of armature.

In order to ensure the uniform, steady running of the car, the wheels are always made with their tread or running faces of chilled or hardened steel, so as to increase their wearing resistance. The wheels are provided with brakes, operated either by hand or by means of compressed air. The compressed air for this purpose is contained within a strong metallic cylinder, placed below the car body, being forced into the cylinder by the action of an

Hand, air, or electric car brakes.

electrically driven pump. This pump can often be heard operating when the car has come to rest. The electric motor which drives the pump is automatically thrown on, and removed from the pump as soon as the air pressure has reached certain predetermined limits. Sometimes a system of electromagnetic brakes is employed. The system of pneumatic brakes, however, gives very satisfactory service.

Sand box.

In order to ensure the adhesion of the car wheels to the tracks during wet weather, especially when these are covered with ice or snow, a small quantity of sand is poured over the track from a box called the sand box, placed where it is readily controlled by the motorman. When the car wheels do not properly adhere to the brake, and thus slip or slide over the track, unless the tread of the wheel has been properly chilled, the wheel is apt to flatten at one or more places. In this way a very unpleasant jarring motion occurs at regular intervals. Unfortunately, when a wheel once becomes flattened, the amount of flattening tends to increase rather than to decrease.

Flat wheels

Car controller.

We will now examine in some little detail the manner in which the motorman placed on the front platform of the car is enabled to start or stop the car, to change the direction of its motion, as well as to vary the speed at which it is moving. This is done by the use of a device called the series-parallel controller, placed on the left-hand side of the car platform, as shown at A, Fig. 268. Here the motorman stands with his right hand on the handle of a hand brake, H, and with his left on the handle of the controller. The series-parallel controller consists of a complex form of switch, by means of which electric connections or disconnections are made by which it is possible to start and stop the car, to reverse its direction, or to alter its speed.

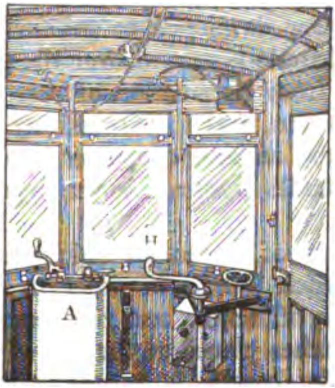


FIG. 268.—Car Vestibule, showing position of series-parallel controllers.

If the front case of such a controller is opened, the inside will appear as shown in Fig. 269, which

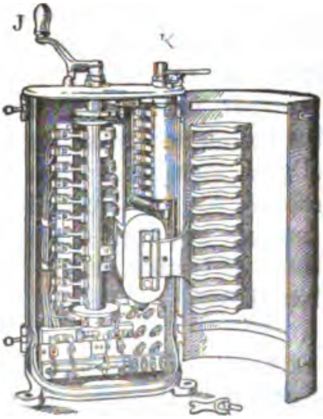


FIG. 269.—Details of Series-parallel Car Controller.

represents a series-parallel controller suitable for a car equipped with two separate electric motors.

Construction and operation of series-parallel controller.

By turning the switch handle J placed in the upper part of the figure, the circuits, both of the separate motors and a number of resistances connected with them, are so varied as to cause the speed of rotation and the power developed to gradually increase as the switch handle is moved over the top of the controller box from its position of rest to its furthest possible position, and to successively decrease such speed and the amount of power developed, as the controller handle is moved in the opposite direction.

Action of the controller outlined.

The amount of movement which it is necessary to give the switch handle in order to ensure certain combinations of motors and resistance coils is indicated by notches placed at the top of the controller box. As the handle is turned, metallic contacts placed on the vertical rod connected with the switch handle are brought into electric connection with other metallic contact pieces, and so the different combinations are effected. Without attempting to enter into a description of this somewhat complex series of connections and disconnections, it will suffice to say that, as the switch handle is moved further and further from its position of rest, the motors are first connected in series with the resistance coils and with each other; then these resistance coils are gradually cut out from the circuit of the motors; the motors are then connected in parallel with each other, and with means for varying the strength of their fields.

Magnetic blow-out of car controller.

Since the strength of the current employed for driving street-cars is fairly great, there is a tendency for powerful arcs to be formed between the various contact pieces on breaking the circuit. In order to prevent these arcs from injuring the controller box by burning out its contacts, an ingenious application has been made of magnetically blowing out the arc as soon as it is formed, by the flux that is produced by an electro-magnet whose coils are traversed by the current that is endeavoring to maintain the arc. In this way it is impossible for dangerous arcs to be maintained, except momentarily.

The switches placed at the bottom of the controller are provided for cutting out one of the motors on the car in case it should become accidentally injured. The small switch handle K placed at the right-hand side of the controller box is for the purpose of reversing the direction of current through the motor armatures, thus changing the direction of rotation, and, consequently, the direction in which the car is driven.

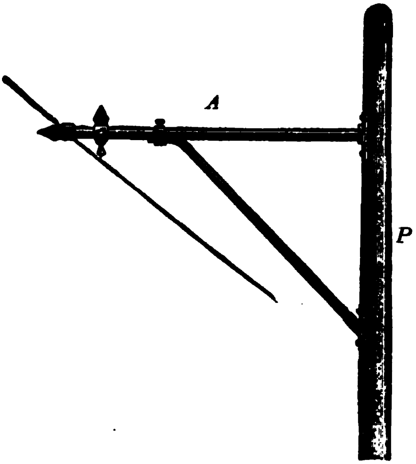


FIG. 270.—Bracket Supports for Single-track Road.

Switches for connecting and disconnecting motors.

There is generally provided on the trolley wires of street-car lines a continuous electric pressure of 500 volts. We will now briefly examine the conductors by means of which this pressure sends an electric current through the motors, and thus drives the car. In the overhead trolley line, the trolley wire or conductor is suspended over the street or road-bed immediately above the track. This suspension is effected by suitable supports placed either on iron or on wooden poles.

Voltage on trolley wire

Where a single pole is employed the wire is suspended by means of brackets. Where only a single track is used the pole P is placed on the side of the track, so that the arm A may project over the centre of the track, as shown in Fig. 270. Where a double-track road is to be provided with trolley wires, the poles are provided with two separate bracket arms, B, B, each of which carries a trolley wire (Fig. 271),

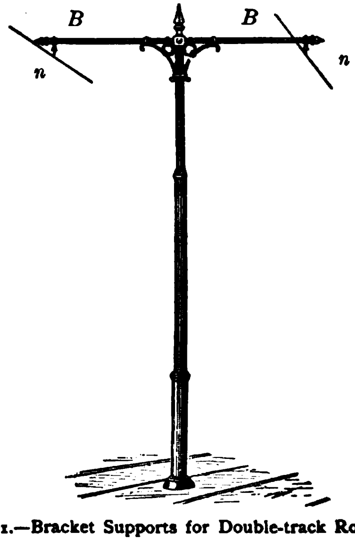


FIG. 271.—Bracket Supports for Double-track Road.

suitably insulated from the poles by means of insulators placed at *n*, *n*.

In the span-wire system of suspension, the poles are placed directly opposite one another on opposite sides of the street or road, as shown in Fig. 272, at P, P, and the span-wire, S, S, S, of iron or steel, is extended from one pole to the other. Insulators *n*, *n*, are provided for the support of the trolley wires where two tracks are employed, or a single insulator where there is but a single track. The span-wires are attached to the poles by means of suitably shaped iron clamps.

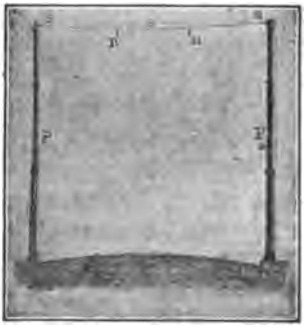


FIG. 272.—Span-wire Supports for Single or Double Track Roads.

Use of span guard wire and running guard wire.

Since the trolley wires are bare or uninsulated should a telegraph or telephone wire, which is also bare, accidentally fall, and come into contact with the trolley wire, dangerous fires may be caused by currents sent through the telegraph or telephone wires. For the same reason, should high pressure electric light or power wires come into contact with the bare trolley wire, a dangerous current may thus be sent into the car. In order to avoid both of these dangers, wires called guard wires are employed.

These are of two different kinds; viz., span guard wires, extending across the street from pole to pole immediately above the trolley wire, and running guard wires, extending parallel with and immediately above the trolley wires. Both of these guard wires are necessary. When properly placed, they practically remove all dangers of accidental contact with the bare trolley wire.

Nature of dangers from trolley wires.

Since, as we have seen, the trolley wire bears a constant pressure of 500 volts, it might, in most cases, send a powerful current through telephone or telegraph wires that accidentally came in contact with it. So far as human life is concerned, it has been found that a constant pressure of 500 volts can, in the majority of cases, be safely borne by the human body, although, in some cases, death has ensued from accidental contact with a live trolley wire. In streets where trolley wires are placed near wires carrying the dangerous arc currents, or transmitting alternating currents, the contact of a trolley-wire with such conductors might readily produce instant death to people touching it. So far as accidental contact with an ordinary live trolley wire by a horse is concerned, death is generally produced by a full discharge of the current through the animal. This is, probably, due to the fact that the iron shoes, placed on the feet of the horse, have removed the protection which nature has given the animal in its non-conducting hoofs; for, the iron shoes, penetrated as they are by wrought-iron nails, convey the dangerous current directly into the body of the animal. In this manner the animal receives a fatal current.

Why trolley currents kill horses.

In order to protect the motors and other electric appliances on the car from lightning strokes, some

Lightning arresters.

form of lightning arrester is employed. These arresters are made of various forms, and consist generally of devices by means of which the high tension discharge from the clouds can pass safely to the ground through a path whose resistance is too high to permit its being traversed by the working current.

Trolley mechanism.

The trolley mechanism for transmitting current from the trolley wire to the car varies according to the character of the system. In a single trolley system, where the track and the ground are used for the return circuit, either with or without regular return conductors, the trolley mechanism consists of the following well-known parts; viz., the trolley wheel, the trolley pole, the trolley base, and the trolley rope. These parts are shown attached to a street-car in Fig. 273. The trolley pole consists generally

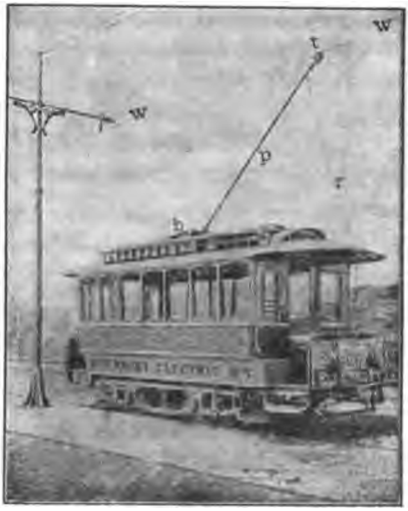


FIG. 273.—Street Car with Overhead-trolley Mechanism. Here *t* is the trolley wheel, *r*, the trolley rope, *p*, the trolley pole, and *b*, the trolley base.

of a steel tube, tapering from the bottom toward the top. This pole is mounted at its lower end on a trolley frame or base, one of the many forms of which is shown in Fig. 274. Here springs, G, are so connected between the base and the pole as to exert a pull against the trolley pole, by means of which the trolley wheel is maintained in a firm pressure against the overhead wire or conductor. The pole and trolley base are supported, as shown, on a vertical axis, V, so as to permit a revolution about its axis, thus allowing the trolley wheel to turn at curves and so follow the trolley wire, as well as to permit the entire trolley mechanism to be reversed when it is desired to change the direction in which the car is to be moved.

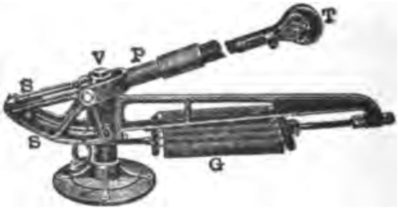


Fig. 274.—Trolley Base, showing attachment of trolley pole. In order to save space the upper end of the trolley pole is represented as being detached.

Shape and action of trolley wheel.

The trolley wheel T is made of gun metal, or other hard wearing metal, and is so supported as to be capable of freely rotating as it is carried forward by the movement of the car. This wheel, as is well known, is caused to press against the under surface of the trolley wire, and to carry off current from it through the conducting pole, and thence, by conductors in the body of the car, to the motors, lamps, heaters, etc. The trolley wheel is deeply grooved, both for the purpose of ensuring a greater contact with the surface of the trolley wire as it rolls under it, and for the purpose of preventing the trolley wheel from being thrown off the trolley wire or conductor. It is found in practice by no means an easy problem to ensure the continued contact of the trolley wheel with the trolley wire, the wheel, under certain circumstances, being frequently thrown off the wire. It is through the trolley base, by means of the flexible contact it ensures between the trolley wheel and the trolley wire, as well as the flexibility ensured to the overhead wire or conductor by the means employed for its support over the street or roadway, that a continuous contact is ensured between the wheel and the trolley wire. The trolley rope *r*, Fig. 273, is for the purpose of drawing away the trolley pole from the wire when it is desired to reverse the direction of the car.

How the trolley is kept on the lower surface of the trolley wire.

Trolley rope.

In most cases the trolley mechanism is designed so as to permit the pole to automatically adjust itself to the varying height of the trolley wire above the top of the car. In cases where very powerful electric currents are employed for driving the motors, as is the case with many electric locomotives, as well as in some other instances, a double trolley system is employed. In this case two separate conductors or trolley wires are placed over the roadbed, and two separate trolley poles and wheels employed. One of these conductors carries the current to one of the poles, and the other carries it back to the power-house, after it has passed through the motors and other devices on the locomotive or car.

Double trolley system.

The overhead system is objectionable in some cases by reason of the very great number of switches that exist in the district over which the car is to run; or the district is one in which legislation has

Under-running trolley system.

forbidden the use of overhead wires. In such cases various expedients are adopted to obtain the current by other means. One of these consists in the underrunning trolley. Here a trolley wire or conductor is placed in a conduit beneath the centre of the car track, and a travelling contact, called the shoe, somewhat similar to the trolley wheel, is connected with a conductor that passes through a slot in the roadbed, and carries the current taken off from the underground conductor by the shoe to the motors in the car.

The third-rail trolley system.

In some cases a system, called the third-rail system, is employed for the collection of the current by the travelling motor. This third rail is placed between the regular tracks, and a cast-iron contact shoe is employed as a travelling contact to take the current from the rail as it is carried over it by the movement of the car. Here the regular tracks are generally employed as the return circuit. Where the third rail system is employed in places like elevated railroad tracks or on private grounds, to which the public have no access, all three tracks are in what is called a "live" condition, that is, are traversed at all times by electric current. In some cases, however, a system is adopted by means of which only that part of the track which lies beneath the train is automatically rendered active by the passage of the train over it. Such a system is called the electro-magnetic system. Here the motor is supplied with current by a number of cast-iron contact-buttons, connected through electro-magnetic switches imbedded in the car track, with a feeder-cable laid on one side of the track. Only those contact-buttons which lie directly beneath the locomotive are active; the rest are dead, so that it is impossible for any one to receive a shock from contact with the conductor.

Electro-magnetic contact system.

Size of trolley wire.

The trolley wire generally employed for railroads using 500 volts pressure is of the size known as No. 0, of the American wire gauge. This wire is approximately $\frac{32}{100}$ of an inch in diameter. It is generally made of hard drawn copper wire, so that the amount of sag, being small, will permit comparatively long spans to be employed between adjacent supports.

Trolley feeders.

In order to decrease the amount of wire necessary to be employed in trolley conductors, a system of feeders is necessary, as in the system of the distribution of current over constant-potential mains for feeding incandescent lamps. In the trolley car feeder system, as shown in Fig. 275, separate conductors, F_1, F_2, F_3, F_4, are connected with the trolley wire at different distances from the power-house. In such a case, the current required to supply the car C, at some distant point of the track, is, in all probability, furnished mainly by the feeder GF_1, the rest of the feeders being comparatively idle so far as this car's supply of current is concerned. The points F_1, F_2, F_3, F_4, where the feeding wires are connected with the trolley wires, are called the feeding points. In rural districts, the feeding wires are generally carried on overhead poles, and within the city limits in underground conductors. Feeding wires are necessarily heavy conductors, so that their location overhead is very unsightly and highly objec-

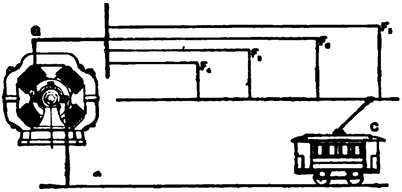


Fig. 275.—Feeder System for Electric Street Cars.

Feeding points.

Underground *vs.* overhead feeders.

tionable. Moreover, it has been found, in actual practice, that, in climates where heavy sleet and wind storms occur, although the expense of locating feeder wires underground is greater at the outset, yet, in the long run, when the expense required to repair the damages done by a single sleet or wind storm is taken in consideration, the system of underground feeders is less expensive.

Good roadbeds necessary.

The heavy cars now generally employed in electric street railways require very substantial roadbeds, and well-laid tracks, in order to avoid injury to the apparatus by jarring and jolting, and to prevent the annoyance arising from the frequent throwing of the trolley wheel off the overhead conductor.

Track and roadbed construction.

In the best construction, heavy steel girder rails are employed for the tracks. These are either laid on the top of wooden sleepers, to which they are attached by spikes, or are placed on longitudinal beams, that themselves rest on sleepers. The roadbed is covered either with Belgian blocks or with cement, on whose surface a thin layer of asphalt is placed. The common practice, now, however, is always to place Belgian blocks along the side of the rails, so as to permit the tracks to be readily reached without tearing up the greater part of the street covering.

Since the rails are employed for the return circuit, in order to reduce the resistance of this circuit at the breaks existing between contiguous rails, some form of rail bond is employed to bridge over this space. Various methods have been proposed for this purpose. At first it was thought that sufficient electric connection could be obtained by joining the ends of the rails by small copper wires, the two tracks also being connected by such wires. Economy of operation, however, soon led to the abandonment of this system of bonding, and now a great variety of bonds have been devised for the more efficient connection of the ends of the rails. That shown in Fig. 276, has heavy copper wires connecting the contiguous rails in the manner shown. These bonds are formed of a number of parallel laid copper wires formed into loops from one continuous strand. Pure copper terminals which are fused on the ends of these loops are then forged to exact size required. The flat parallel wires give great flexibility to the joint, allowing for expansion and contraction of the rails without undue strain on the terminals.

Rail bonding.

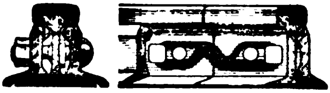


FIG. 276.—Form of Coil Bond and Protected Rail Bond.

So important is the thorough electric connection of contiguous street-car rails that plans have been adopted for actually welding the ends of the rails together, thus practically ensuring the presence of a single continuous conductor for the return circuit. In such cases powerful electric currents are passed between the ends of the rails sufficient to raise them to a welding temperature, and pieces of iron, called chucks, which are employed in place of the regular fish plates between contiguous rails, are at the same time so heated by the passage of the current that they become welded to the rail, the whole forming one continuous metallic piece. Another method, which is somewhat similar, and which ensures a practically continuous ground return, consists in obtaining a solid bond between the ends of the rails by pouring cast metal, or a metallic alloy, in between

Electric welding of rails at joints.

a metal piece, suitably placed in the position of the ordinary fish plate.

Electrolytic corrosion.

The necessity for obtaining a good electric connection between the ends of the rails, and thus ensuring a practically continuous ground return of the circuit, not only arises from the required economy of working, which demands as small a resistance of the return circuit as possible, but is also necessary for the purpose of avoiding a tendency to destroy neighboring gas and water pipes by a process known as electrolytic corrosion. The amount of this corrosion can be rendered practically insignificant by ensuring a good electric ground return, and this a good bonding system does.

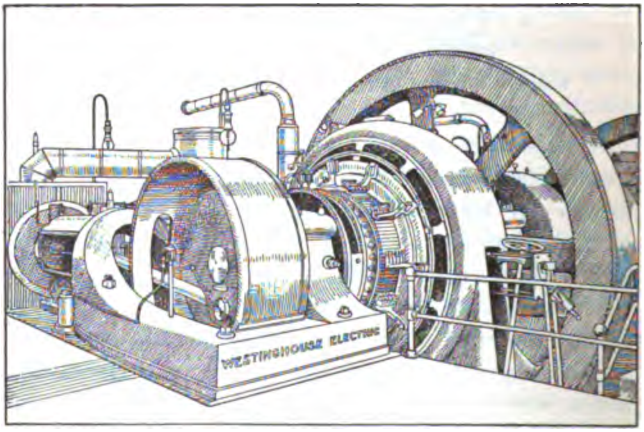


Fig. 277.—Direct-connected Railway Generator, Westinghouse Company's Type.

Railway generators.

The street-car system now in general use requires a large amount of electricity to drive the cars. In other words, the output of the central power stations, where such current is generated, must necessarily be very large. This current is produced by specially designed and constructed dynamos or generators, called street railway generators. In all large stations, a number of large generators are required. A street railway generator, of the Westinghouse Company's type, of fairly large size, is shown in Fig. 277. This generator is of the direct-connected type, and is compound-wound, being over compounded, so that the potential at its terminals increases about 10 per cent from no load to full load. The shunt and series coils are separately wound, so that they can be readily removed.

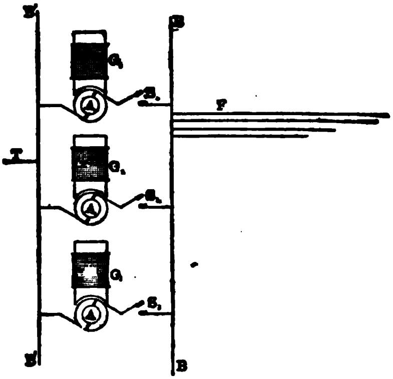


Fig. 278.—Connections of Generators to Bus-bars and Feeders at Central Power-house.

Connection of generators to bus-bars and feeders at central station.

The separate generators of the power-house are connected at the switchboard to two main conductors, called bus-bars. This is seen in Fig. 278, where, for purposes of simplicity, only the bus-bars and the connecting switches are shown. Here, as will be seen, three generators are placed in multiple between the bus-bars B B, and B' B'. As the load on the station increases, the different generators can be connected to the bus-bars by means of the switches shown at S_1, S_2, S_3. The bus-bar BB is connected with the feeders at F, while the bus-bar B'B' is connected with the track and the ground-return circuit as shown.

Electric car heaters.

As is well known, the heating and lighting current for the car is taken from the trolley wire. The electric car heaters are generally placed on the side of the riser below the car seat, a number of separate heaters being employed on each side of the car. In order to ensure a proper ventilation, the air that passes through the electric heater should be taken from outside the car.

Street railway incandescent electric lamps.

The incandescent electric lamps employed on street cars are of the particular railway type already described, being carefully anchored to prevent breakage of the filaments from the jarring and jolting to which they are exposed. As the electric pressure on the trolley wires is generally in the neighborhood of 500 volts, these lamps are placed across the mains in series, *i.e.*, to conductors connected with the trolley wire and the track respectively, the number of such series-connected lamps depending on the particular voltage employed in the lamp. Switches, placed in convenient positions in the car, enable the lamps to be readily turned on or off.

Canopy switch.

There is generally placed on every street-car a switch, called the canopy switch, which is provided for the purpose of enabling the current to be shut off from the car in case of accident. In some car systems, this switch is replaced by an automatic electro-magnetic circuit-breaker, by means of which, should a current attempt to pass through the motors stronger than they are capable of bearing, an electro-magnet releases the switch handle, and thus cuts the current off from the car, in which case the conductor or motorman is able to at once turn it on again by resetting the switch. This switch is always provided with a magnetic blow-out, for the purpose of preventing the maintenance of a dangerous arc.

Automatic railway circuit-breaker.

We have thus briefly treated of some only of the conveniences that are found on the ordinary electric street car. Enough has been said, however, to show how great an improvement this system of transportation is over any of the old methods employed for carrying passengers from one part of a city to another. In some cars, a system of an electro-magnetic call bell, operated by push buttons placed in convenient positions alongside the seats, has been introduced, for the purpose of calling the attention of the motorman or conductor to the desire of a passenger to have the car stop.

Electro-magnetic call bells.

CHAPTER XXXIV

ELECTRIC LOCOMOTIVES

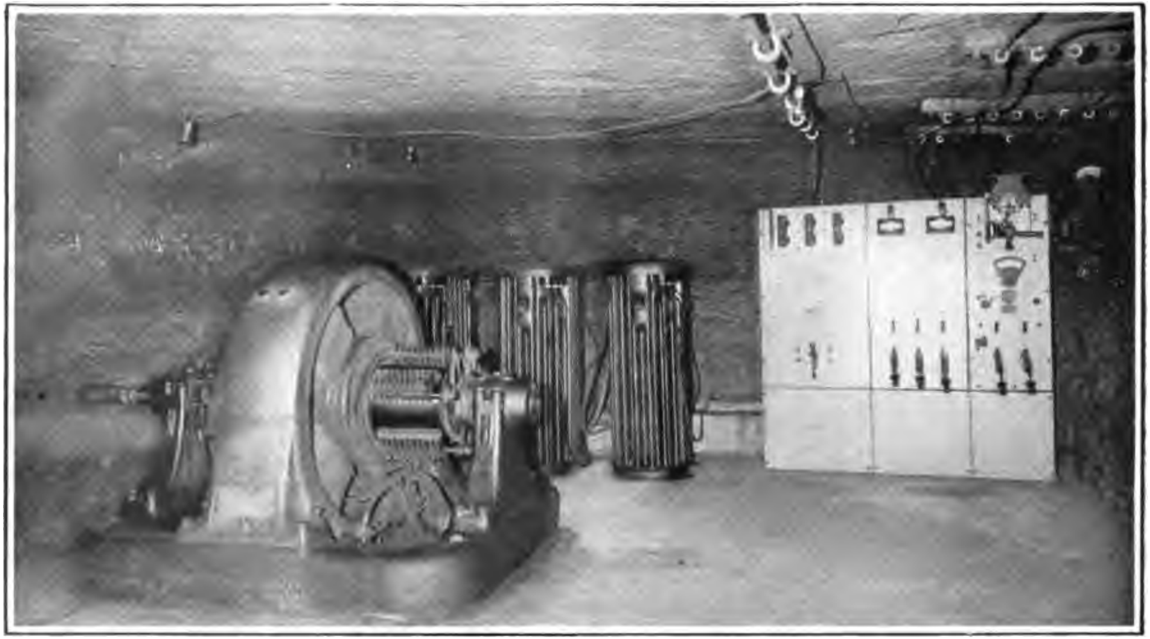
> "On many of the large steam railroad systems in the United States, there are certain sections which present the most favorable conditions for the substitution of electricity for steam as a motive power. These conditions are the result of increasing density of population, and mean that better and cheaper transportation facilities are needed by the public than are provided by the steam road."—*Notes on Electric Traction under Steam Railway Conditions:* EDWARD C. BOYNTON

Electric locomotive or electric locomotors.

STRICTLY speaking, an electric locomotive is a movable electric motor, or locomotor, and this is true whether such motor be placed on a structure resembling the ordinary locomotive, on a street car, or on a boat. Generally speaking, however, by an electric locomotive is meant a structure driven by electric motors, that is intended for drawing a train of cars, employed for the transportation either of freight or passenger cars. In addition to the above, electric locomotives are very generally employed on short lines of railroad for switching purposes at the terminals of the road. They are also extensively used in various industrial establishments, such as steel plants, lumber mills, iron furnaces, and other similar localities, for general hauling purposes.

Where electric locomotives are especially serviceable.

Electric locomotives are especially serviceable in railroad tunnels, where the smoke or steam escaping from a steam locomotive would render the confined air of the tunnel unfit to breathe, and, in all probability, would greatly increase the mortality in case of accidents occurring in the tunnel. They are read-



ELECTRICAL POWER IN A MINE

A sub-station of the power plant of a mine. Electricity plays an important part in mining operations to-day. Among the later developments, electric locomotives are now used in many mines to haul out trains of ore cars

ily employed in districts where water power is abundant, on account of the ease with which electric power can be distributed; for, here, a single generating station can readily be employed to furnish the current necessary to drive a number of separate electric locomotives.

Some advantages of electric locomotives

Generally speaking, an electric locomotive, capable of drawing a given load over a track, can be built of much smaller weight than can a steam locomotive, which must carry its engines, coal, water supply, and boilers. A marked advantage arising from the employment of electric locomotives lies in the fact that they are less apt to cause fires in surrounding property than steam locomotives. This is of considerable value in the case of such locations as lumber mills, plantations, oil refineries, or similar locations where fire risks are great.

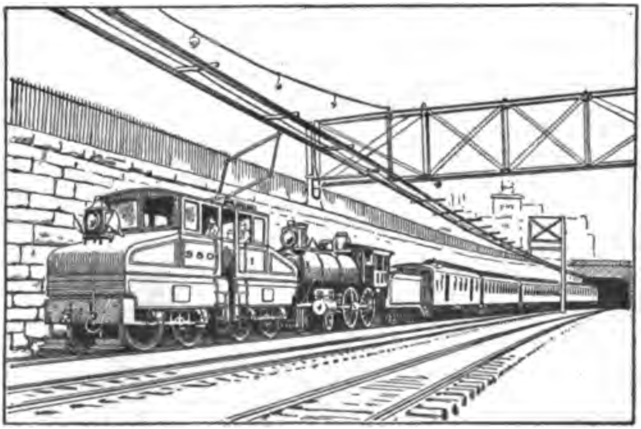


Fig. 279.—Electric Locomotive on the Baltimore & Ohio Railroad Drawing Heavy Train and Steam Locomotive through its Tunnel.

In Fig. 279, is shown an electric locomotive, constructed by the General Electric Company for the Baltimore & Ohio Railroad. This locomotive is represented as drawing the Royal Blue express train,

B. & O. electric locomotive.

a heavy, first-class passenger train, out of the tunnel. This particular locomotive is one of the largest in the world, and is equipped with 4 gearless, 360 horse-power, sextipolar motors. This locomotive can readily haul trains weighing, approximately, 1,900 tons, on an 8 per cent grade. Although only designed for hauling, yet it was able, on one occasion, to attain, without any load, a speed of 60 miles an hour.

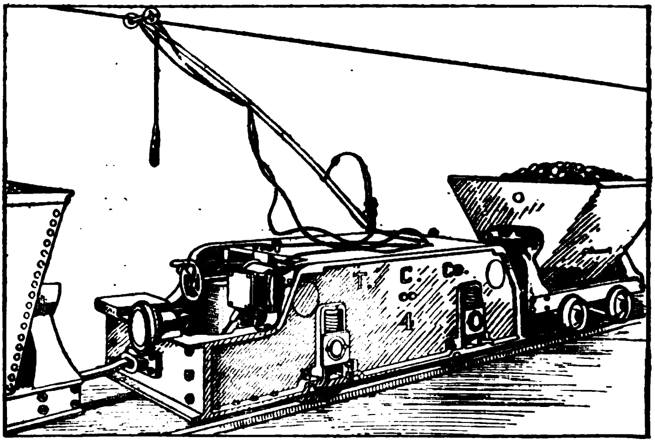


FIG. 280.—Locomotive Built by the Baldwin Locomotive Works and Equipped by the Westinghouse Electric Company for the Tennessee Copper Company.

Possible compactness of the electric locomotive.

The possibility of placing the electric driving motors in a very small space renders it easy to give to the electric locomotive a compactness that would be impossible in the case of the steam locomotive. This compactness renders the electric locomotive especially serviceable for hauling cars in spaces where the height is limited, as in the tunnels of mines. This is shown in Fig. 280, in the case of the locomotive employed by the Tennessee Copper Company. This locomotive is employed for charging furnaces and handling slag cars on a dump.

For heavy haulage, the electric locomotive is generally equipped with powerful air brakes, for the sudden stoppage of the train when so required. The air for this purpose is contained in a metallic cylinder placed underneath the car, the air being forced into the cylinder by the action of an electric motor. The brake is applied to the tread of the wheel by means of the well-known form of pneumatic brake.

Air brakes.

As in the case of the electric street car, the motors of the electric locomotive are controlled either by the aid of a series-parallel controller of the type already explained in connection with electric street cars, or by a rheostatic control, through the aid of which the motors, permanently in parallel, may be connected in series with resistances. These resistances are gradually cut out of the circuit by the movements of the controller handle. Various speeds are obtained by varying the amount of resistance left in the circuit of the motors. A magnetic blow-out is employed as in the case of the street-car motors, to prevent the maintenance of dangerous arcs. The resistances generally employed in connection with locomotive controllers are shown in Fig. 281. Here

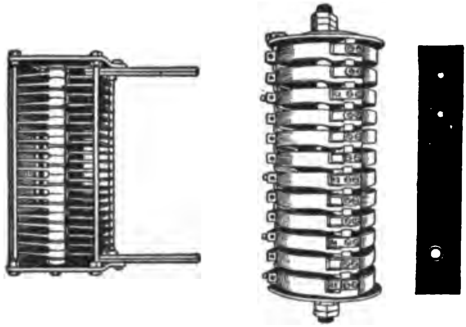


FIG. 281.—Forms of Resistances employed in the Controller of Electric Locomotives.

Use of controllers on electric locomotives

Forms of resistances employed in the controllers.

two forms are represented. That at the top of the figure, called the ironclad cell, consists of a strip of sheet metal wound in a spiral form on an iron core, the successive layers being insulated by a sheet of mica. A number of these cells are mounted on the section of an insulated tube, and are held together by nuts, so as to form a column, as shown in the figure. The other form of resistance is called the grid diverter, and is represented at the bottom of the figure. It consists of a number of cast-iron plates, mounted together in the form of a cell, and separated by washers of mica, thus permitting space for the ventilation of the resistance.

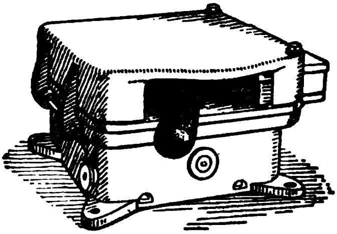


FIG. 282.—Automatic Railway Circuit-breaker.

Automatic railway circuit-breaker.

In order to protect the motors and other apparatus on the car from the effect of too powerful currents, an automatic railway circuit-breaker is employed. Its general appearance is seen in Fig. 282, which represents a 500-ampère circuit-breaker. When the current passing through the coils of a magnet placed in this circuit-breaker exceeds a certain predetermined strength, the attraction of an armature automatically opens the circuit of the car. At the same time, a magnetic blow-out instantly extinguishes the arc that tends to form on the sudden breaking of the circuit. The circuit is then re-established by the motorman moving the handle shown in the figure.

Double trolley for electric locomotive.

In electric locomotives, where a large current is employed, a double trolley is generally used, such as is shown in the form of locomotive represented in Fig. 283. In Fig. 284, a form of electric freight locomotive, of the General Electric Company's type, is shown. This locomotive is employed on the Buffalo & Lockport Railroad. The driving power is supplied through transmission lines from Niagara Falls. Two 165 horse-power, geared motors are

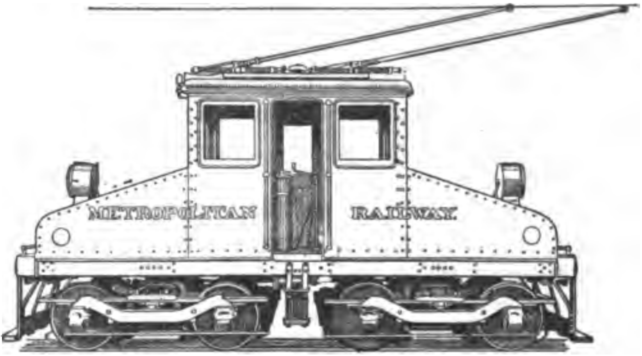


Fig. 283.—Double Trolley on Electric Locomotive of the Metropolitan Railway.

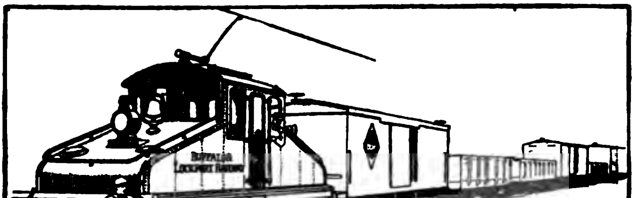


Fig. 284.—Electric Locomotive employed on the Buffalo & Lockport Railroad.

mounted on each of the trucks, so that the locomotive can develop 660 horse-power. A series-parallel controller is placed in the cab for the control of the speed, and for starting and stopping. Here, as in the case of electric locomotives generally, an air whistle is employed, the air for this purpose being compressed in a cylinder by means of an electric motor. The locomotive is provided with two electric headlights.

Air whistle for locomotive.

The Central Underground Railway Company, of London, is now installing some 28 separate electric locomotives for drawing its passenger trains. Owing to the fact that the underground tunnel is only 11 feet 6 inches in diameter, it is necessary that the locomotive cabs be made low, so that they can readily clear the top of the tunnel. The plans for these locomotives, which are now under construction by the General Electric Company, is for a 2-truck, 8-wheel locomotive, each truck being provided with two 200 horse-power, gearless motors, direct connected to the truck axles, so that each axle is a driving axle. Consequently, this locomotive is capable of exerting 800 horse-power; its speed equal to about 40 miles an hour. It is interesting, in this connection, to note that this particular railway is of the third-rail type, the current being taken from a third rail by means of contact shoes mounted on each side of the locomotive.

Equipment for Central Underground Railway Company of London.

Third-rail type of road

CHAPTER XXXV

TELPHERAGE

"Drawn with a train of little atomies."
—*Romeo and Juliet,* Act I, Scene IV

IT is asserted, although on doubtful authority, that many years ago, when the practical applications of electricity and magnetism were not as well understood by the general public as they are to-day, an Irishman, desiring to send a pair of top boots to his brother, hung them up on a telegraph line, and was both disappointed, and had his faith in the applicability of electricity to everyday life considerably shaken, by finding that they were still hanging in the same place on the next day. Too much ridicule, however, should not be directed against this original experimenter in the electric art of telpherage. Had he lived in these later days, his method for transporting articles would not at all have been an impossibility; for, by means of a comparatively recent invention, articles that are practically so hung on conducting lines can be carried far to a distance from the place from which they are sent.

The Irishman and his early experimentation in telpherage.

It was Prof. Fleeming Jenkin, of England, who was among the first to propose this curious method of electric haulage, and coined the word telpherage, now generally applied to it. Although the system of telpherage was originally limited to the method of carrying packages on an overhead wire, it is now frequently applied as well to some kinds of surface,

Professor Fleeming Jenkin, of England.

and even of underground, traction. Broadly speaking, a telpherage system consists of means for the conveyance of goods, merchandise, or various forms of raw material, in bulk, in carriages suspended from electric conductors that are generally overhead. The carriages are propelled over the conductors by means of electric motors that take their current directly from the conductor, or receive it from overhead trolley lines, as in the case of electric street railways. The telpher track, over which the telpher car moves, is made either of cable, of solid bars, or in the form of flat girders. In the case of cable tracks, the track is supported every hundred feet or so, at least in all cases where such suspension is possible. Where, however, the line extends across deep ravines, or between the higher stories of factories, a longer span is sometimes necessary. The cable track is hung by means of suspension cables from suitable hangers, the number of hangers depending on the distance between intermediate supports.

Telpher track.

Suspension cables and hangers.

As a rule, telpher lines are of comparatively limited length. Originally, all telpher lines consisted of an elevated road, formed of a wire cable, on which electrically propelled cars ran. In some cases, the cars take their current from another conductor placed above them. In most cases, the advantages of a telpher line consist in the readiness with which such line is erected, and, consequently, the cheap cost attending its erection. For example, in Fig. 285, is shown a telpher line employed for the purpose of conveying limestone from a neighboring quarry to the cement works, where it is manufactured into hydraulic cement. Here a double line of comparatively cheap and simple construction is erected between the quarry and the works. As the buckets

Some advantages of telpher lines.

are filled at the quarry, the telpher, with its bucket hanging below it, is passed along the line, as shown in the figure. Reaching the mill, the bucket dumps its load and passes around the loop, returning to the quarry for another load. In the meanwhile, other buckets, with their telphers, are being loaded and sent over the line. With this type of line, practically any distance can be passed over, though generally, as already stated, such lines are not made of very great lengths.

Telpher line between quarry and cement works.

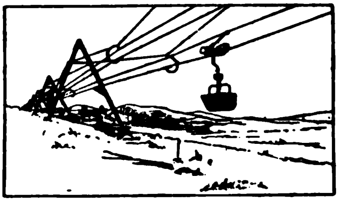


FIG. 285.—Telpherage employed between Quarry and Cement Works.

In some cases, however, the telpher line takes the form of a simple elevated electric railroad. This is the case in the following method, which has been devised by the United States Telpher Company for

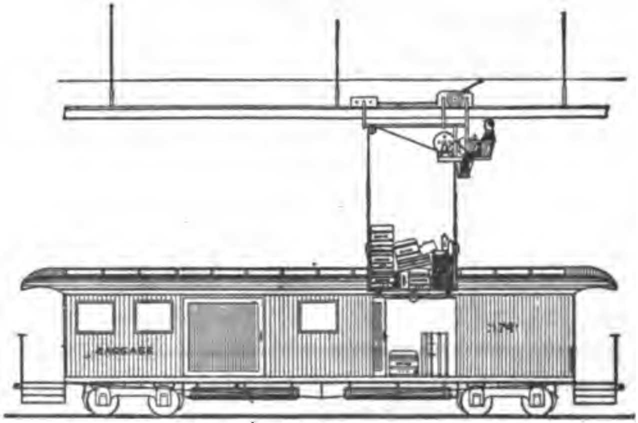


FIG. 286.—Baggage handled by Telpher Line.

Baggage smashers or telpherage baggage handling.

the purpose of conveying trunks and other baggage from a baggage car to the baggage rooms at the car depot. Here, as shown in Fig. 286, a telpher car moves over a telpher track immediately over one side of the car track, so that, on the arrival of the steam-car train, the electric motor connected with the hoist lowers the truck immediately at the door of the baggage car. This arrangement enables the baggage to be conveniently transferred from the baggage car to the truck. When the truck is loaded with trunks, the electric hoist raises the truck to the necessary height, and the telpher car then carries the load of trunks to the baggage room.

Ashes handled by telpher.

In Fig. 287 is shown the application of the telpher system to the carrying of ashes, or other similar refuse. In this particular case, the ashes from some 73 boilers, together with other refuse, are handled

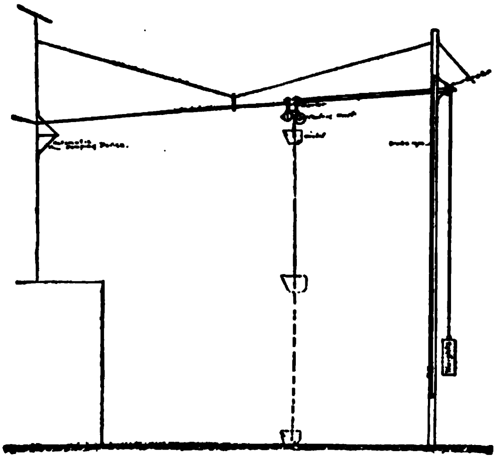


Fig. 287.—Ashes and other Refuse handled by Telpher Line. Note that here the load is raised by means of an electric hoist, conveyed by gravity and returned by means of a counterweight.

by this system, which is capable of handling 150,000 lb. of ashes every ten hours.

Electric hoisting and the alternate action of gravity and counterweight.

Where the distance to be passed over is very small, such as might exist where material is to be raised from a pavement or platform and dumped into a shoot near the top of a storehouse, the movement of the car may be obtained by the alternate action of gravity and of a counterweight as is shown in Fig. 288. Here, when the bucket is filled with its load, it is raised to the necessary height by means of an electric hoist. Matters are so arranged that the weight of the hoist, bucket, and load is greater than that of the counterweight. Consequently, on releasing the rope, the bucket descends to the building where it is automatically dumped at the shoot. As soon as this occurs, the counterweight, which is now heavier than the hoist and the empty bucket, returns the bucket to its first position, where it is lowered and again filled and hoisted. The speed is under the control of a hand brake.

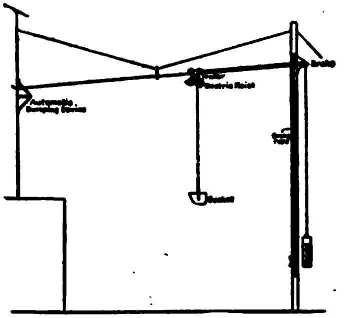


FIG. 288.—Alternate Use of Gravity, Counterweight, and Electric Hoisting in Placing Material in Storehouse.

CHAPTER XXXVI

TESLA AND THE MULTIPHASE MOTOR

"Ferraris and Tesla, in 1888, discovered, independently, the rotary field motor, worked by multiphase alternating currents."
—PREECE

IF King Solomon at his early day could truly exclaim, "There is nothing new under the sun," how much truer must this be at the beginning of the Twentieth Century? Although, by reason of hard work, combined with that rare gift known as genius, one man may sometimes make such an advance as to get considerably ahead of his competitors, yet it seldom happens that he can make a discovery or invention so absolutely new that he can fairly claim it as entirely his own. This is especially the case, as we have already seen, in other parts of the domain of electric science.

The experience of Solomon.

The wonderful invention of the multiphase electric motor forms no exception to the general rule. In this invention, as in nearly all great inventions, we can not pick out a single individual and fairly ascribe to him the honor of having, unaided and alone, placed the invention in the state in which it is ready to be put into the every-day service of man; for here, too, it will be found that there are others who can properly claim a fair share of such honors.

The multiphase electric motor the work of more than one.

Without going at length into the early history of the multiphase motor, it must suffice to say that there are several men who can properly claim a share in this great invention. These are Bailey, Ferraris. Bradley, and Tesla. Of these early inventors, the names of Ferraris and Tesla stand unquestionably ahead of the others. These inventors, independently of each other, invented the multiphase motor at practically the same time. If a choice is to be made between them, there can scarcely be any doubt that the merit for the most important work should be given to Tesla.

Bailey, Ferraris, Bradley, and Tesla.

Tesla in the front rank in this invention.

Pioneer work in this field was carried on by Walter T. Bailey. As early as June 28, 1879, Bailey presented to the Physical Society of London a working model of a motor that he described in a paper entitled "A Mode of Producing Arago's Rotations." It will be remembered that in Arago's experiments a copper disk had a motion of rotation imparted to it by means of an electro-magnet, rotated above the disk. In Bailey's motor the copper disk was rotated by means of a fixed electro-magnet containing four poles, the magnetism of which was caused to shift successively. Although this early motor contained the germs of the invention of the multiphase motor of to-day, yet it can hardly be regarded as suitable for actual commercial work, unless, indeed, such work were limited to the mere driving of a copper disk for the purpose of determining the amount of current that passes in any circuit. In other words, while the Bailey motor might have served as a form of electric meter motor for determining the quantity of electricity that passes in a circuit, it could hardly be regarded as being as applicable for the purpose of driving heavy machinery as are the multiphase motors of to-day.

Bailey's early forerunner of the multiphase motor.

Professor Galileo Ferraris constructed an electric motor embodying the principles of the multiphase

Galileo Ferraris.

motor as early as 1885. He published an account of this motor in 1888, and exhibited it at the World's Fair at Chicago in 1893.

Charles S. Bradley's multiphase motors.

Charles S. Bradley filed an application in the United States Patent Office for a multiphase motor on May 8, 1887. In this specification, he described the use of two separate alternating electric currents for driving the motor that differed in phase by 90°. He does not, however, make any reference to the presence of a rotating magnetic field, which, as we shall shortly see, is necessary for the operation of a multiphase motor. He subsequently took out another United States patent, dated August 20, 1887, in which a motor is described as operated by means of three alternating currents, differing in phase in such a manner as to constitute a three-phase current.

Nikola Tesla.

The work of Tesla in the field of multiphase motors was unquestionably more complete than that of Ferraris, and was sufficient by itself to produce commercially operative multiphase motors. We will, therefore, describe the multiphase motor in the light of Tesla's inventions, bearing in mind, however, the claims of others to a part of the honor of this great invention.

Nikola Tesla, a Serbian, was born in 1857, at Smiljan, Lika, on the borders of Austria-Hungary. His great discovery resulted in the production of a particular form of electric motor, now generally known as the multiphase or polyphase electric motor. In this electric motor neither commutator nor brushes are employed.

Although Tesla was ridiculed by those to whom, at an early date, he made known his belief that neither brushes nor commutators were necessary to operate a motor, yet he continued in his efforts to accomplish this desired end, until, after many years of continuous labor, he succeeded in producing, as early as 1887 and 1888, multiphase motors that possessed efficiencies as high as any of the direct-current motors then in existence. To-day, motors practically of the same type, are extensively used in all parts of the world.

Tesla's early beliefs as to simplified motors.

A system of multiphase alternating electric currents consists of two or more conductors that are traversed by independent alternating currents, that differ from one another by a definite difference of phase. Of the great number of possible multiphase alternating currents, there are practically only two that are generally employed; viz., the diphase and the triphase alternating currents. Diphase alternating electric currents consist of two separate alternating currents, that differ from one another in phase by ¼ of a cycle or 90°; while triphase alternating currents consist of circuits having three alternating currents, differing from one another in phase by 1-3 of a cycle or 120°.

Multiphase alternating current systems.

Diphase and triphase currents possess certain advantages as regards the operation of motors, especially when taken in connection with systems for the transmission of power over great distances. We will, therefore, examine some of the peculiarities of diphase and triphase alternating electric currents. Let us take, for example, the diphase current circuits represented in Fig. 289, in which there are two separate circuits that receive simple alternating currents from the same dynamo at A. These separate alternating currents are exactly alike, save that the current in the circuit *abcd* differs from that in the circuit *efgh*, in that the E.M.F.'s that produce these

Advantages of diphase and triphase currents for operating electric motors.

currents differ in phase by ¼ of a cycle, the waves reaching their greatest values or highest crests in one circuit at the moment that they are at their smallest values or their lowest crests in the other circuit. This difference in phase is obtained by so placing the armature coils on the alternator in which they are produced, in such a position, as regards one another, that this difference of phase must result.

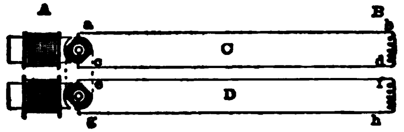


Fig. 289.—Diphase System of Current with Four Conductors.

Diphase system with three conductors

It is not necessary, however, in order to transmit diphase currents through any distance, to provide the four separate circuits shown in the above figure. A common return conductor may be employed in place of the conductors *cd* and *ef*, of Fig. 289, as shown in Fig. 290, where a diphase, three-wire system is represented. In this case, since the conductor *cd* transmits a greater current strength than either *ab* or *gh*, it is necessary to make its area of cross-section somewhat greater than that of these conductors.

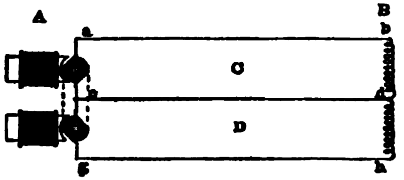


Fig. 290.—Diphase System with Three Conductors.

In the same manner, a triphase system of alternating currents consists of three separate and distinct alternating currents produced from a single generator, and connected with three separate and distinct circuits *abcd*, *efgh*, and *ikml*, Fig. 291, differing from one another by 1-3 of a cycle or 120°.

Triphase system with six conductors

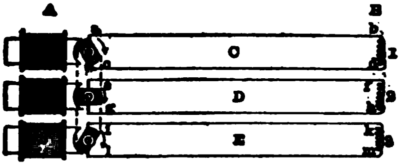


FIG. 291.—Triphase System with Three Conductors.

Here, however, as in the case of the diphase circuits, it is not necessary to employ six distinct conducting wires to transmit triphase currents to a distance, since each wire can serve as a common return conductor for the other two. Consequently, such circuit can consist of three conducting wires only, as shown in Fig. 292.

Triphase system with three conductors

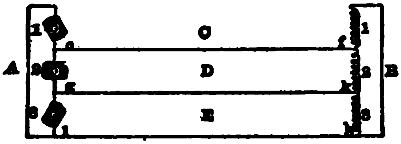


FIG. 292.—Triphase, Three-wire System.

Let us now examine the manner in which multiphase alternating currents are employed for the operation of motors. We will take the simpler case of the diphase currents, and will suppose that an iron ring ABCD, Fig. 293, is wound with insulated wire, and supplied first with two separate, direct currents, applied respectively at AB and CD. There are then produced two magnetic poles, that will remain fixed in position as long as the direct currents continue to pass through the magnetizing coils. If, however, two separate diphase currents be supplied, one at AB, and the other at CD, then there would be produced magnetic poles that would regularly revolve around the ring, and would tend to carry a compass needle around with them.

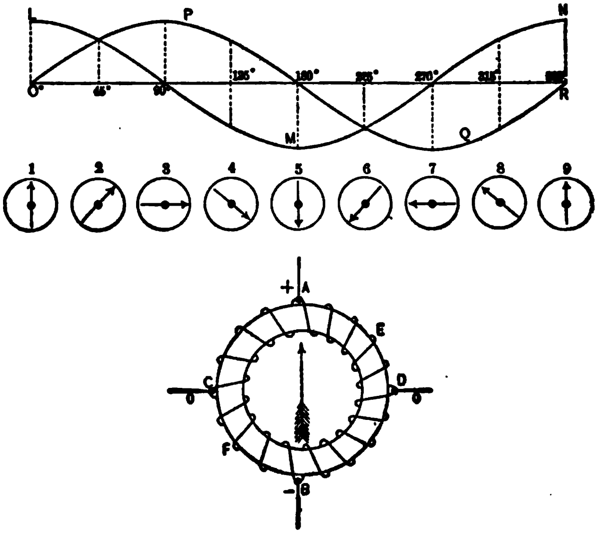


FIG. 293.—How a rotating Magnetic Field is produced by a Diphase-current System.

Production of a rotating magnetic field by diphase currents.

Consider, for example, what would take place at the moment when the two diphase currents were in the phases indicated at the upper part of the figure; *i.e.*, the conductors connected with the current LMN, being connected to the ring at A and B, and those connected with the current OPQR, being connected at C and D. At this moment there is no current passing through CD, so that AB only acts and tends to produce the north and south poles indicated in the figure. Consequently, a magnetic needle, placed inside the ring, would tend to point in the direction of the large arrow shown inside the ring, or of the small arrow at 1, in the middle part of the figure. At exactly ¼ of a cycle from this position the current in LMN has now fallen to zero, while the current of OPQR has reached its greatest value. Consequently, magnet poles will be produced at C and D, and the magnetic needle will point in the direction indicated at 3, at the middle of the figure. At the end of ½ a cycle, or at 180°, the current in OPQR has again reached the zero value, while that in LMN has again reached its maximum, but this time in the opposite direction to the maximum it had at the start, so that the magnetic needle now tends to point in the opposite direction, or as indicated at 5, at the middle of the figure. For similar reasons, the needle would point, at positions 7 and 9, in the directions indicated. In the intermediate positions at 45°, 135°, 225°, and 315°, both alternating currents are acting, but at different phases, so that the needle will tend to point as indicated at 2, 4, 6, and 8, at the middle of the figure. The combined results of these various actions would, therefore, produce on the magnetic needle, during each cycle, an effect that would cause the needle to be carried around continuously, by the shifting resultant field, as long as the ring was supplied with diphase currents. The field thus produced is called a rotating magnetic field, there being produced one complete rotation for every cycle of the alternating currents.

One complete magnetic rotation per cycle.

It is on the principle of the rotating magnetic field that multiphase current motors are operated. The magnetic needle, placed inside the iron ring, wound with insulated wire, as shown in Fig. 293, constitutes, in point of fact, such a motor in miniature, being called a synchronous multiphase motor, since its armature revolves in exact synchronism with the phase of the currents that are driving it. When,

Synchronous multiphase motors.

instead of a needle or something that corresponds to a needle, a cylinder of laminated iron is employed, wound with conductors just like the conductors on the armature of a dynamo, except that they are short circuited, such an armature will also revolve under the influence of the rotating magnetic field. In this latter case, however, its speed will be somewhat less than that of the synchronous armature, the difference of speed, which is called the slip, generally amounting to from one to five per cent. This slip means that the close-circuited armature conductors possess a motion with respect to the rotating magnetic field. Consequently, since such conductors cut the lines of magnetic flux, they will have electric currents induced in them. It is the mutual interaction of the magnetic flux of the rotating field, and the magnetic flux of the field produced by these currents, that causes the armature to revolve. A motor of this character is called a multiphase induction motor.

Induction motors.

The great value of multiphase induction motors lies in the fact that, since no current is directly supplied to the moving part, there is no necessity for any electric connection between the field and the armature, except, indeed, for purposes of starting and regulation. As in ordinary alternating-current dynamos, either the part in which the current is induced revolves, or is stationary. Therefore, the terms rotor and stator are respectively applied, in the case of the multiphase induction motors, to the parts that revolve or are stationary, just as in the case of direct-current machinery, already referred to.

Reasons for value of induction motors.

Rotor and stator.

Triphase alternating currents produce rotary magnetic fields in a similar manner to diphase currents, and are able to produce multiphase motors both of the synchronous and of the induction types, multiphase synchronous motors possessing the advantage over ordinary single-phase motors, in that they are capable of starting from a state of rest. Multiphase induction motors, moreover, unlike the single-phase motor, possess considerable torque at starting, and, therefore, do not require any special device in order to bring them up to synchronism.

Multiphase synchronous and induction motors.

A multiphase induction motor, of the Westinghouse Company's type, is shown in Fig. 294. This size of motor is capable of producing 500 horsepower. The great simplicity of such a machine will be seen from an inspection of the figure. It consists, essentially, of but two elements; viz., of the primary or stator, the part that is directly magnetized by the current supplied from the triphase power circuit, and the secondary, or rotor, in which low potential currents are induced by the action of the primary. The windings of the primary are such that, when supplied with triphase alternating cur-

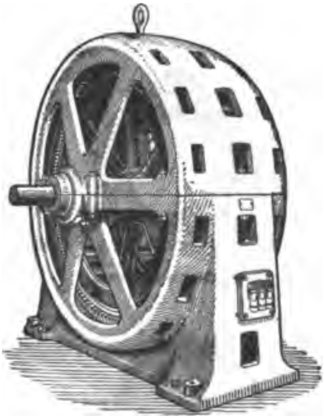


FIG. 294.—Multiphase or Polyphase Induction Motor, Westinghouse Company's Type.

Multiphase induction motor, Westinghouse Company's type.

rents, a rotating magnetic field is produced. This rotating field acts on the secondary winding, and induces currents therein, and, in this manner, a rotation is produced by the interaction of the fields of the two circuits.

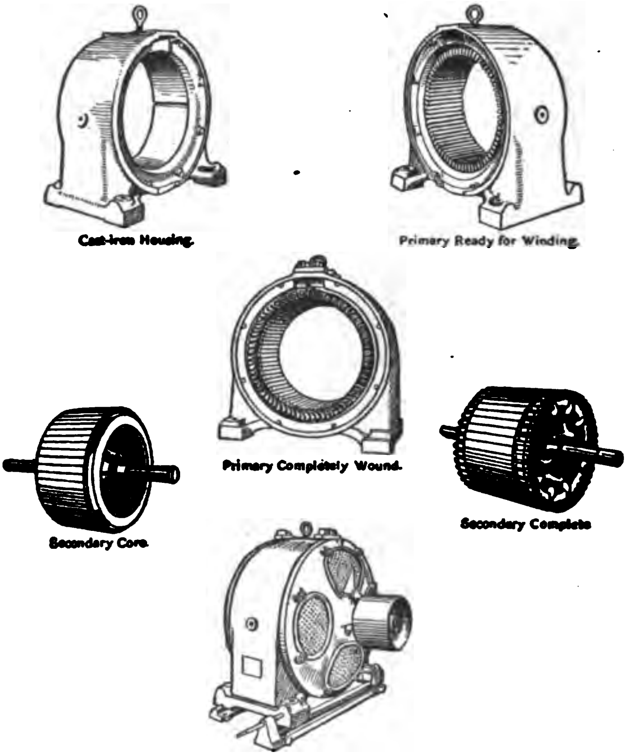

Cast-iron Housing.
Primary Ready for Winding.
Primary Completely Wound.
Secondary Core.
Secondary Complete.
Type "C" Motor Complete.

FIG. 295.—Different Parts of Multiphase Induction Motor, Westinghouse Company's Type.

Various parts of multiphase induction motor.

The various parts of a multiphase induction motor, of the type just described, are shown in Fig. 295. Here the primary element consists of a cast-iron housing, that incloses the primary and forms the frame of the motor. It consists of a hollow cylinder, built up of laminated rings of sheet metal, slotted on the inside, as shown, for the purpose of receiving the conductors. These rings are rigidly supported by the cast-iron housing. Where the motors are of large size, the rings are not continuous, but are made up of segments. The conductors of the primary are generally machine-wound coils of wire, that are thoroughly insulated before being placed in the slots of the primary iron core. In some of the larger sizes of motors, instead of wire coils, a copper strip, bent in the proper form, is employed inside the coils. In some large motors, wound for low voltages, and, therefore, in which a large current-carrying capacity is necessary, the windings consist of copper bars placed in each slot, the necessary connection between the bars being made by short lengths of copper strap. The appearance of the completely wound primary is seen in the centre of the figure.

Secondary core of multiphase induction motor.

The secondary core is built up of laminated disks of steel, suitably mounted on a spider. It carries the rectangular copper bars, employed for the winding, in partially closed slots on its periphery. The complete motor is shown at the bottom of the figure. These motors are designed either for two-phase or three-phase circuits, and for 7,200, 3,600, or 3,000 alternations per minute. The standard voltages are 200 or 400 volts up to sizes of 200 horse-power, and 400 volts for larger sizes of motors.

Some peculiarities of multiphase induction motors.

In multiphase induction motors, the variation in speed between no load and full load is small. The motor is capable of being overloaded for a short time without sensible damage, since it contains no commutator to be injured by sparking, and no moving part to be burned by arcs. The only manner in which it can be injured is by the overloading of the coils, and these are readily made of such current-carrying capacity that they can, as already stated, safely carry considerable overloads, if not continued for too long a time.

Auto-starter for multiphase induction motor.

A multiphase motor of small size can be started by directly connecting its terminals with the driving current. When of large size, it is necessary to start it at some smaller voltage, the full E.M.F. only being applied when the motors have nearly attained their full running speed. The low E.M.F. required for this purpose is obtained from a small machine called an auto-starter. This consists, as shown in Fig. 296, of a double-throw switch, placed on the top of an iron box, in which are two transformers. When the switch is thrown in one position, the two transformers are placed across the circuit, and fur-

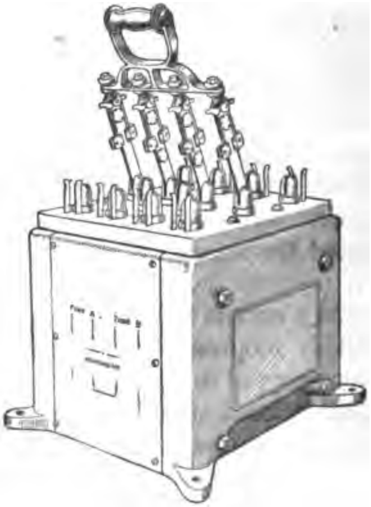


FIG. 296.—Starting Device for Multiphase Induction Motor.

nish the low E.M.F. required for starting. As soon, however, as sufficient speed has been attained, the switch is thrown in the opposite direction, thereby cutting out the transformers, and connecting the motor directly with the driving circuit.

Motors started at a distance.

It is not necessary that the starting device for a multiphase motor be placed near the motor. On the contrary, it may be placed at a distance from it. This is especially advantageous in such cases as woollen mills, flour mills, or other places where combustible materials exist, and where, consequently, a danger might arise from fires caused by possible sparking at the contacts of the switches.

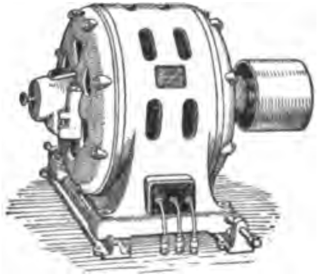


Fig. 297.—Induction Motor with Starting Resistance, General Electric Company's Type.

Induction motor with starting resistance.

The multiphase induction motor is sometimes provided with a starting resistance, placed inside the motor's secondary or armature. Such a motor, of the General Electric Company's type, capable of furnishing 40 horse-power, is shown in Fig. 297. As in the case of the direct-current motors, multiphase motors can be placed either on the floor, on the wall, or on the ceiling. Indeed, this is especially true of induction motors, since, as we have seen, they have neither commutator nor brushes, and, consequently, require but little attention.

CHAPTER XXXVII

SOME APPLICATIONS OF THE ELECTRIC TRANSMISSION OF POWER

> "The economical radius of direct-current supply from a central station is so limited that even in a strictly direct-current system, if it covers considerable area, recent engineering prescribes a large alternating-current generating plant furnishing power to rotary converter sub-stations, and from these the direct current is distributed. This is witnessed in recent installations in Greater New York."—*Alternating Current in General Distribution:*—CHARLES F. SCOTT

Basis for the electric transmission of power.

GENERALLY speaking, the electric transmission of power is based on the fact that, when electricity is sent through a dynamo or generator, it causes it to be driven as a motor, so that it becomes a source of mechanical power. This is true of all types of generators, whether direct, single-phase, or multiphase. If, therefore, a generator of any type be located at a distant source of power, such, for example, as a water-fall or a steam-engine, the mechanical energy required to drive this dynamo at this point can be transformed into electric energy, and this electric energy can be transmitted over a line wire or conductor, and be reconverted into mechanical energy at the receiving end of the line, by causing it to pass through a second generator of the same type as that at the generating end of the line.

As we have seen, the distance over which such transmission is possible is limited only by the size of the conductor that connects the two stations.

Given a wire of sufficient conducting power, practically any distance can be overcome. In point of fact, large amounts of energy are being transmitted every day in California over a distance that is in the neighborhood of 250 miles. While either direct or alternating currents can be employed for such transmission, yet the many advantages possessed by alternating currents, especially those in regard to the ease with which their pressure can be increased or decreased, and their applicability to the driving of motors, have caused nearly all transmission lines to be those in which multiphase electric currents are employed.

Distance of possible transmission only dependent on conducting power of circuit.

The following example of the great saving in the cost of copper, that is possible even in the case of but a fairly high pressure on the transmission line, will make it clear why alternating currents at high pressures have practically entirely replaced direct currents at low pressures for the electric transmission of energy. Triphase generators can be readily wound directly to produce fairly high pressures. Suppose, for example, that triphase currents are employed on a transmission line at a pressure of 6,600 volts. Under these circumstances, a given amount of energy can be transmitted over a given distance with the use of less than one per cent of the copper that would be required in order to transmit the same amount of energy over the same distance by the use of a direct current at a pressure of 550 volts.

Great saving in weight of copper on transmission lines at high pressure.

Many different systems of multiphase transmission have been installed in actual, every-day use. Both diphase and triphase alternating currents are employed, but, generally speaking, the tendency is to employ triphase currents, from the fact that the

Some advantages of triphase transmission.

quantity of copper required to transmit a given amount of electric energy over a given distance is much less than that required in the diphase system. Moreover, the triphase system is less complex than the diphase.

Low-pressure transmission.

A variety of triphase transmission circuits are in use. In some cases, the generator delivers triphase currents direct to the transmission line at comparatively low pressures. The E.M.F.'s at the generator terminals are sufficiently above those required by apparatus at the receiving end of the line to make up for the loss during transmission. Of course, in such cases, the distance of transmission is not very great, so that it is possible, economically, to employ low pressures over the transmission lines.

High-pressure transmission with step-down transformers.

Where the length of the line is greater, the generators produce triphase currents at very high pressures, and deliver such currents to the transmission lines. At the receiving end of the line, step-down transformers are employed to lower the pressure to that required for the motors, lamps, etc. This is practically the system employed in all long-distance transmissions.

High-pressure transmission with transformers at each end of line.

In some cases, the generators are wound for producing currents at low E.M.F.'s, and step-up transformers are employed to raise the pressure to that required for economical transmission. As in the previous case, step-down transformers must be employed at the receiving end of the line to lower the pressure for the lamps, motors, etc.

It will be interesting to give examples of the three different systems of electric transmission above referred to. The low-pressure system is suitable for

Low-pressure transmission system.

factories and other similar plants, where the distance of transmission is not great. Such a system is represented in Fig. 298, where a triphase induction motor is shown near the generator, provided with a pulley, and intended for the belt driving of some piece of machinery. An alternating-current arc lamp is shown connected to two of the phases. At the end of the circuit a small triphase induction motor has its shaft directly connected to the shaft of a continuous-current dynamo, which produces the continuous current required for the operation of the plating bath, with which it is connected. The dotted line in this figure is intended to indicate the connection of incandescent lamps to the circuits of a diphase transmission circuit of the four-wire type.

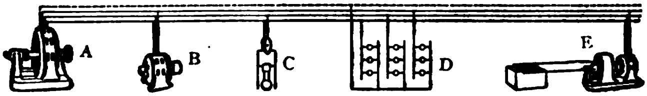


FIG. 298.—Low-pressure Transmission System. Here A is the generator, B a triphase induction motor, C an arc lamp, D incandescent lamps; at E is a triphase inductor directly connected to a continuous-current motor, operating a plating bath.

High-pressure transmission system.

In Fig. 299, a multiphase transmission plant is represented, in which a triphase generator is wound to produce a pressure of say 2,300 volts. This pressure is suitable for direct use on large motors. Incandescent lamps and smaller motors, however, must

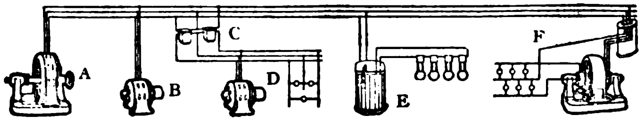


FIG. 299.—High-pressure Transmission System with step-down transformers. A, triphase generator; B, large motor; C, step-down transformer; D, small motor and incandescent lamps; E, constant-current transformer; F, step-down transformer, motor, and lamps.

have their pressure lowered by the use of suitable step-down transformers. At the centre of this figure is shown the use of a constant-current transformer, in connection with four arc lamps connected in series, as shown. This is the system we have already described. In this case, two of the phases of the transmission line are connected to the primary windings of the transformer, and with the arc lamps in series, as shown.

Where the distance of transmission is great, generators of a large size are wound for furnishing pressures as high as 13,000 volts. This system is the one that is employed by nearly all lighting and power stations to-day.

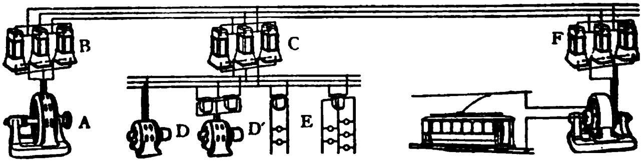


Fig. 300.—Very High-pressure Transmission Line, with Transformers at each end of the Line. A, triphase generator; B, step-up transformer; C, substation with step-down transformers; D, induction motor; D′, induction motor for pressures lower than D; E, incandescent lamps; F, sub-station with step-down transformers feeding rotary converter, which supplies street-car system.

Transmission system with transformers at each end of the line.

Where the distances are so great that 13,000 volts are not sufficient, then the remaining system described is employed. Here the dynamo is wound for any convenient electric pressure, and the pressure is increased, by means of step-up transformers, to any higher pressure required, say 20,000, 50,000, or 60,000, volts. In such a system, step-down transformers are employed at the place where the transmitted currents are utilized. A system of this character is shown in Fig. 300. Here the generator produces any convenient difference of potential at its terminals, and this pressure is greatly increased by means of step-up transformers, shown at the left-hand side of the figure, one transformer being connected to each phase. The advantage of such a transmission line lies in the fact that a number of sub-stations can be supplied with current at various points along the line. In the case shown in the figure, two only of such sub-stations are represented, one intermediate between the two ends of the line, and the other at the far end of the line. At the sub-station that is nearer the dynamo, three step-down transformers are employed to lower the pressure for the triphase motor shown connected to the transformer terminals. Here, too, a second set of step-down transformers are employed for still further lowering the pressure for the incandescent lamps and most of the motors.

Rotary converter.

In the sub-station shown at the far end of the line, there is seen an application that is now coming into general use. Here a set of three step-down transformers are connected, one to each phase, so as to lower the pressure for use in an apparatus called a rotary converter, that is employed to change the alternating currents to the direct currents required for use in street-car propulsion.

High-pressure transmission for street-car lines.

In an extended street-car district, instead of having a number of central power stations distributed throughout the district at distances apart depending on its different densities of population, it is far more economical to have a single central power-station at which alternating currents of high pressure are generated. These high-pressure alternating currents, which are generally triphase in character, are then transmitted over a well-insulated line to various sub-stations, where the high pressures are first reduced by passing the currents through step-down transformers, and are then converted into direct currents, at pressures of from 550 to 600 volts, by the use of rotary converters.

Advantages of high-pressure transmission for street-car system.

The advantages attending this use of a central power station, connected at suitable distances along the transmission line with sub-stations, are many. In the old plan of erecting central stations where direct currents were generated at pressures which permitted such currents to be passed directly to the trolley wires or conductors, the position of such stations was necessarily determined by the amount of current that such station was expected to produce, the distance at which it could economically supply outlying districts being limited by the amount of copper required in the feeders and conductors, as elsewhere indicated in similar cases of direct current supplied through constant-potential mains. A necessity, therefore, existed in such systems of locating the central station at a point approximately in the centre of the district to be supplied, and this often necessitated the erection of such station in a district where land was dear and where an extra handling of the coal required for the power was necessary. In a system of high-pressure alternating currents, however, this central location of the power plant is no longer a matter of consequence, so that the plant can be located in a district where land is comparatively cheap, and where the power can be produced under far more economical conditions.

Main power station can be situated anywhere in district.

Complex and expensive nature of generating station.

It is well known that, at any central station, a considerable space is occupied by the boilers, steam-engines, and other appliances necessary for the production of the current. Moreover, at such stations, a variety of electric appliances is also necessary.

All these things necessitate the expenditure of considerable sums of money. Moreover, the number of attendants required for the operation of a central station is great, thus necessitating a big pay roll. Now, where a single, large, main power-station is erected, these expenses can be considerably reduced, since at each of the sub-stations the apparatus installed requires comparatively little attendance, one man, as a rule, being able to take care of the several rotary converters employed, and even then to have some spare time for other work. Besides all this, the operation of such a sub-station is unattended by noise or danger, and is less objectionable when located even in high-class resident neighborhoods.

Simple character of sub-stations.

But there is still another reason why a number of small sub-stations are better suited for street railway systems than a few large, independent central power stations, employing direct current. Great variations or fluctuations in the total load of such a central station, that, as has already been pointed out, are apt to occur at certain hours of the day, are far less apt to occur in the more limited areas that are assigned to a number of smaller sub-stations. Consequently, these stations can be of a smaller capacity as regards their total output than would be necessary in the case of a direct-current central station, since a single extra or reserve rotary converter could carry the extra load called for by ball games, parades, fairs, excursions, and other causes that require an increased load for but a limited time.

Load more uniform at sub-stations

The circuits and apparatus of an electric streetcar system, where triphase generators are employed at the central power station, with step-down transformers and rotary converters at the sub-station, is

Three-phase distributing system for electric street cars.

shown in Fig. 301. Here we find a central, or, as it is now more proper to call it, a main, power station, with the triphase alternating current generators wound so as to produce the high E.M.F. necessary for direct connection to the transmission circuits. Such pressures will vary from 6,500 to 15,000 volts, according to the character of the district to be supplied by the triphase currents. In such cases, any type of triphase generator may be employed. The form shown in this figure is that of the revolving field type of triphase generator, since this form more readily permits the production of the high-pressure currents that are required for this character of transmission.

Revolving field triphase generator.

An examination of the above figure will show that the triphase currents produced by the revolving field generators pass directly to a switchboard. Such boards consist of two distinct parts; viz., the part which is connected to the oil circuit breakers, which act as switches, and which are placed in separate brick compartments, and the operating panels, which only are, in general, accessible to the attendant at the sub-station. These operating panels are connected with the ground and feeder wires after the pressure has been reduced, by the step-down transformer and the rotary converter, to the five hundred odd volts required for the operation of the cars in those portions of the district that are supplied by this sub-station. It will be observed that the system represented in this figure is a system of street railways employing a third rail, so that the direct-current circuits, after leaving the rotary converter, are connected with the third rail and the feeder cable in the manner represented.

Switchboard at triphase generating station.

At each sub-station, only two of which are shown in addition to the station connected directly with

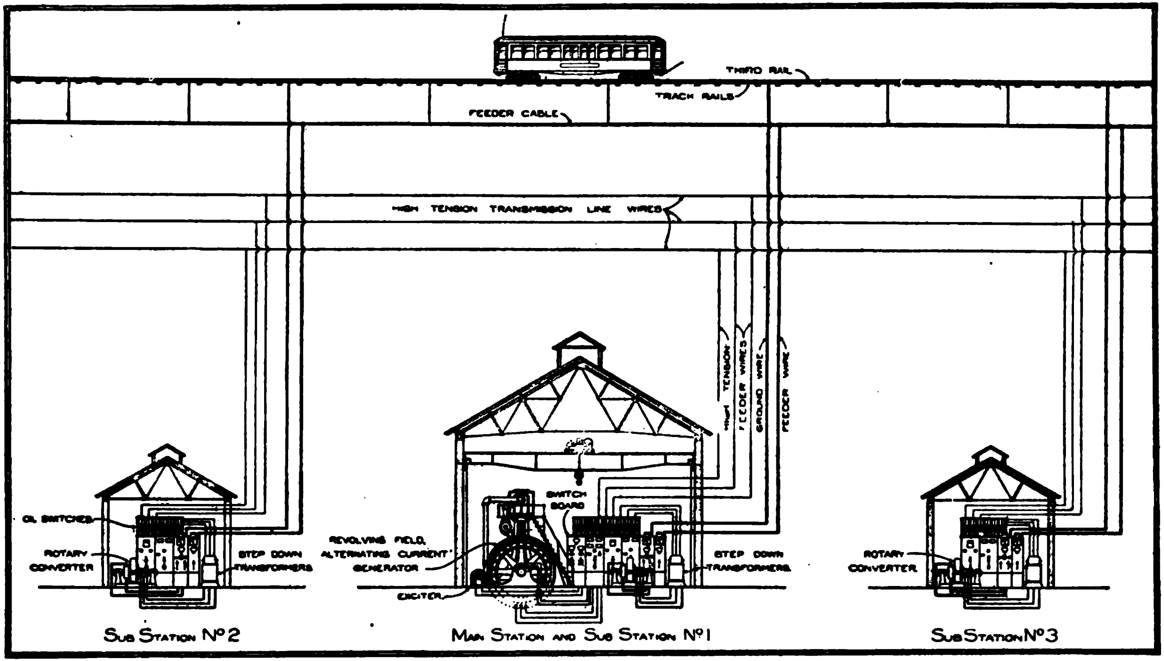


FIG. 301.—Distribution System for Street Cars.

the main station, the same arrangement of apparatus, as regards the high-pressure currents, taken from the triphase transmission lines, is employed, the oil switches and step-down transformers being placed separate and apart from the working panels of the switchboard. It will be seen from the figure that each sub-station consists practically of a separate brick inclosure containing the oil switches, and connected with the step-down transformers; and the room containing the rotary converters that take the current from the step-down transformers and transmit it to the working line through a working panel of the direct-current switchboard.

General arrangement of sub-stations

We will now consider the construction and operation of the rotary converter, by means of which the triphase electric currents are changed to direct currents of the neighborhood of five hundred volts, after their pressure has been sufficiently lowered by the use of step-down transformers. A rotary converter consists practically of a motor and a dynamo combined, the motor being driven by suitable electric currents taken from one circuit, which may be called the primary circuit, and the dynamo delivering current into another circuit, which may be called the secondary circuit. The motor may be driven either by means of direct or alternating currents, so that the dynamo may deliver either direct or alternating currents, either at the same pressures or at different pressures. In all cases, however, the total amount of electric energy; *i.e.*, the watts, or the product of the volts by the ampères, will be somewhat less in the secondary circuit than in the primary circuit, owing to necessary frictional and other losses that occur during the conversion. Apparatus of this general character may take a variety of forms.

Rotary converter.

The motor and the dynamo may be mechanically connected together on the same shaft. An unfortunate lack of uniformity formerly existed as regards the names given to this piece of apparatus, which has been variously called a dynamotor, a motor dynamo, a motor transformer, a rotary transformer, a motor converter, and a rotary converter. In order to bring about a uniformity in the use of names for apparatus of this character the Committee on Standardization, of the American Institute of Electrical Engineers, have proposed names for this type of apparatus that are now generally adopted by electrical writers. In accordance with this suggestion, the apparatus consisting of a motor and a generator, mechanically connected together, is called a motor-generator. A motor-generator, of the General Electric Company's type, is shown in Fig. 302. Here the alternating part of the apparatus is seen at the right-hand side of the figure, and the direct-current part on the left-hand side.

Committee on Standardization on names of apparatus.

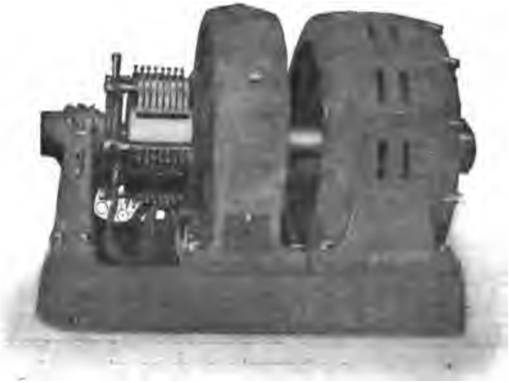


FIG. 302.—Motor-generator, General Electric Company's Type.

Motor-generator.

Sometimes the transforming device consists of both motor and dynamo, placed in one magnetic field, either with two separate armatures, or with a single armature on which are two separate windings. Such a machine is now called a dynamotor. As these machines are generally operated, the direct current required is obtained by employing alternating currents to drive the motor side of the apparatus, and taking the direct current from the direct-current generator. It is evident, however, that the reverse of this operation would be possible.

Dynamotor

Another form of transforming device consists of a machine in which the same armature windings play the part of both motor and dynamo. Such a machine is now generally called a rotary converter. The action, by means of which it is possible to obtain the required results from a single armature winding will be seen from an inspection of Fig. 303, where a ring core is wound with the usual ring winding. Two collecting brushes, A and B, are connected to portions of the winding directly opposite each other. When this ring armature is placed in the bipolar fields N, S, shown in the figure, and supplied with direct current in the usual way, by brushes placed at + and —, the armature will revolve as a motor, and alternating currents can be

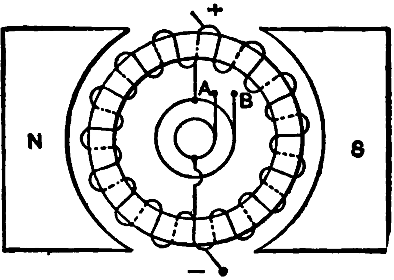


FIG. 303.—Action of Rotary Converter.

Rotary converter.

taken from the collecting rings A and B. In the same manner, if alternating currents are fed to the armature through the collecting rings A and B, this armature will also revolve as a motor, and a direct current can be taken from the brushes at + and —. As the apparatus is arranged in the figure, uniphase alternating currents will be supplied from the armature when it is driven as a motor by the direct current. In order to obtain diphase or triphase alternating currents, it is only necessary to tap the armature windings at four equidistant points for diphase currents, and at three equidistant points for triphase currents.

How to obtain diphase or triphase currents.

Where a rotary converter is employed to produce direct current, by supplying it with single-phase alternating currents, the converter is operated as a synchronous motor. In such cases it is necessary to bring the converter up to speed by the use of a separate motor, but where the converter is driven by diphase or triphase currents, as an induction motor, no such extraneous driving is necessary in order to bring it up to speed.

Starting a rotary converter.

A triphase rotary converter, of the General Electric Company's type, is shown in Fig. 304, where the alternating-current side is at the right of the machine, and the direct-current side at the left. The armature of this converter is wound in the same manner as the winding of a direct-current generator. The field winding is also similar to the direct-current generator, and may be either shunt-wound or compound-wound. The sparking at the commutator side of rotary converters is far less pronounced than in the case of direct-current dynamos. Several rotary converters can be operated in parallel. Two rotary converters can be operated together in series

Triphase rotary converter.

for three-wire systems of distribution, provided the alternating currents are supplied from separate secondary circuits.

Marked flexibility of rotary converter.

The rotary converter is a marvellously flexible machine, and affords an admirable example of the readiness with which alternating and direct currents can be converted into each other, or can be varied as regards their pressure. Consider, for example, the number of possible uses to which a rotary converter is capable of being put; viz., when supplied with alternating currents it will deliver direct current; when supplied with direct current it will deliver alternating currents; when connected to alternating-current mains it will act as an alternating-current motor; when connected with direct-current mains it will operate as a continuous-current motor; when driven by mechanical power, as a generator, it will deliver alternating currents that may be either single-phase, diphase, or triphase, according to the type

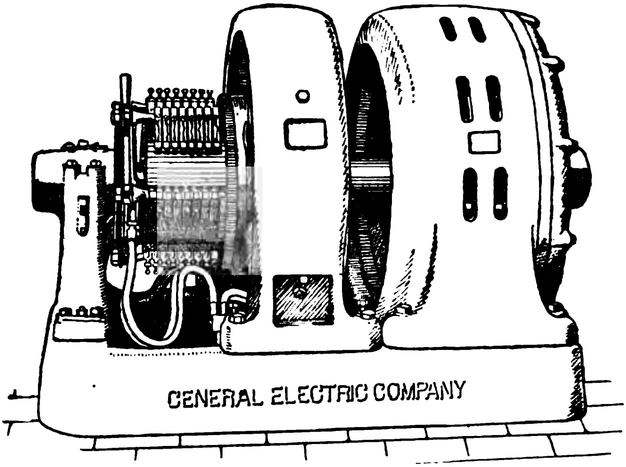


Fig. 304.—Triphase Rotary Converter, General Electric Company's Type.

of the converter; when driven by mechanical power, as a generator, it will deliver direct currents; when driven by mechanical power, as a generator, it is able to deliver, at the same time, both alternating and direct currents; when connected with continuous-current mains it will deliver mechanical power from its pulley, and yet, at the same time, it will deliver alternating currents from its collector rings; finally, when connected with alternating-current mains, it will deliver mechanical power from its pulley, while, at the same time, it is furnishing electric current from its commutator.

Delivers alternating and direct currents.

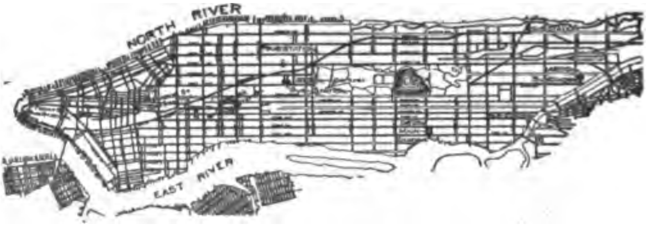


FIG. 305.—Map of the Metropolitan Street Railway System of New York City.

The advantages of the high-pressure triphase-distribution of current, for street-car lines, and other purposes where direct current is required, has led to the employment of such a system in a number of large plants, and it would appear that similar systems will soon come into general use. It will be interesting, therefore, to examine somewhat briefly into the details of a system now in operation. We will take, for this purpose, the case of the Metropolitan Street Railway of New York City. This great electric street railway system covers a territory that is represented in the map shown in Fig. 305. It includes all the surface car lines on the island of Manhattan. The main power-house or station is situated on the East River, at 96th Street.

System of triphase distribution of current on the Metropolitan Railway of New York City.

The revolving field type.

Here are installed eleven huge triphase generators, of the revolving field type. These generators are wound for a pressure of 6,600 volts. Each generator is directly connected to a 5,000 horse-power compound-condensing engine, and is capable of delivering 3,500 K. W. each. The switchboard, which is situated at one end of the main station, together with the various circuit-breakers on the low-pressure side, are distributed among several galleries, so as to separate them, as far as conveniently possible, from one another, and thus afford plenty of room around them for working. Each generator is controlled, as regards being switched into or out of the circuit, by means of oil circuit-breakers, that are controlled by air pressure. Each oil circuit-breaker is located in a separate brick compartment, so as to protect the other switches should a dangerous arc form at one of them.

Details of sub-stations.

In each of the sub-stations there are from three to six rotary converters, of 990 K. W. capacity each, together with step-down transformers of the air-blast type, for reducing the pressure before supplying the current to the rotary converters. These converters are built to supply direct current, at a voltage of 550 volts, to the trolley wires in the open conduit system employed on this road. The Metropolitan Street Railway operates some 1,200 electric cars on 80 miles of track.

Another instance of the electric transmission of power is found in the system of electric plowing. Such a system is represented in Fig. 306, where the electric plow takes its driving current from readily movable trolley lines that connect with the generating plant by the line shown in the figure. In order to save time in the replacing of the temporary trolley

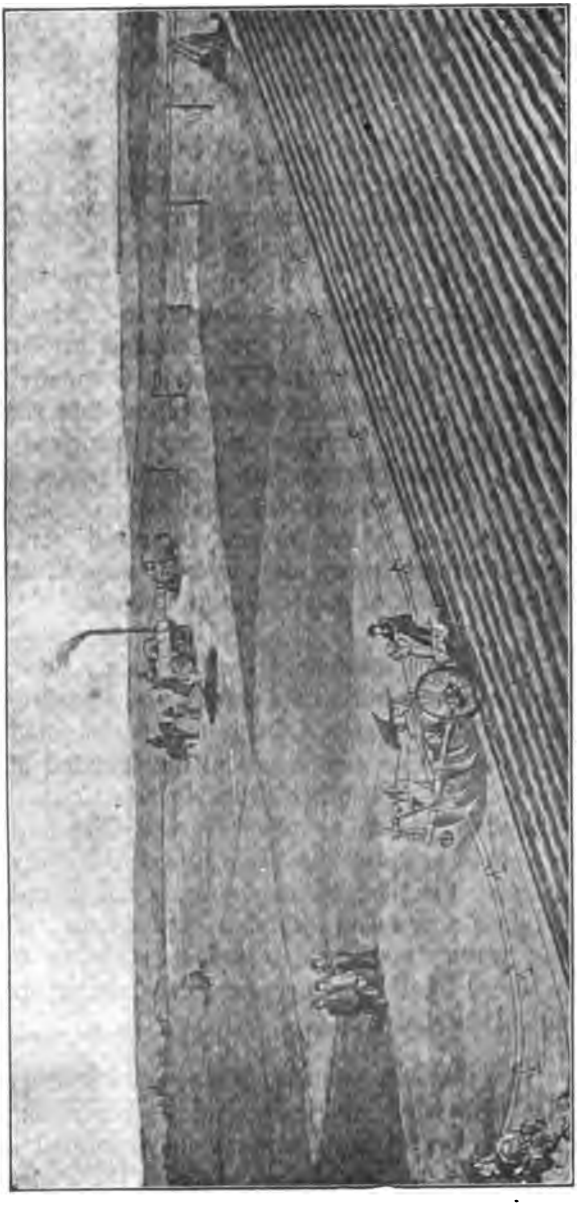


FIG. 306.—Electric Plow in Operation in Germany.

line, the plow is so constructed as to cut three furrows simultaneously. This plow operates somewhat faster than the ordinary man can walk.

Electric plowing.

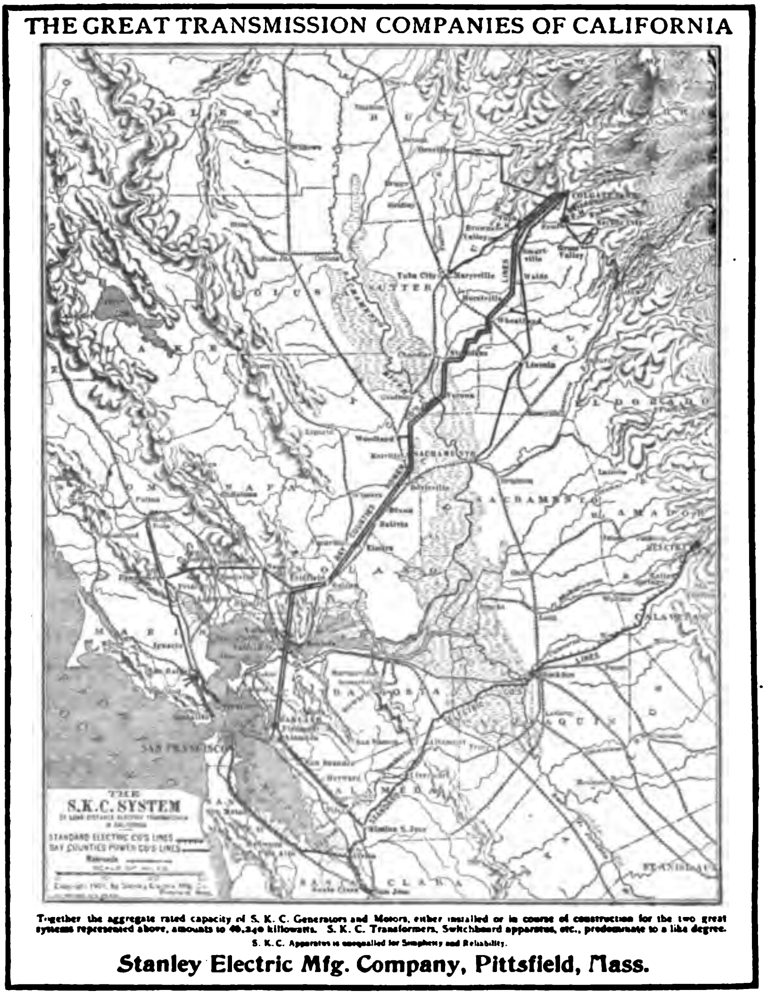
One of the best examples of long-distance transmission of electric power is found in the case of the Standard Electric Company's and the Bay Counties Power Company's lines in California. A map of this district is given in Fig. 307. The Bay Company's lines extend from Colgate to Oakland, a distance of 152 miles. From Oakland to San Francisco, by the Standard Electric Company's lines, there is an additional 70 miles, so that the entire distance from Colgate to San Francisco is 222 miles. From Mission San Jose, the power is transmitted backward over the Standard Company's lines to Stockton, where several thousand horse-power are distributed every day, at a distance of 218 miles from its point of generation at Colgate.

California district supplied by electrically transmitted power.

The Bay Counties Power Company was formed by the combination of a number of separate electric transmission plants. Originally it consisted of the combination of two small plants situated about 30 miles from each other—the Nevada County Power Company, which supplied Nevada City and neighboring towns, and the Yuba Power Company, which adopted the plan of employing a fall in one of the irrigation canals or ditches, saving the tail-water, for water is a most valuable article in countries where irrigation is necessary, for the irrigation of the lower districts.

Bay Counties Power Company.

In a somewhat similar manner, the Standard Electric Company practically had its beginning in the Blue Lakes Water Company, incorporated some 31 years ago for supplying water to the mines in the neighborhood. This company had constructed an elaborate ditch system of more than 80 miles in



THE GREAT TRANSMISSION COMPANIES OF CALIFORNIA

Together the aggregate rated capacity of S. K. C. Generators and Motors, either installed or in course of construction for the two great systems represented above, amounts to 40,240 killowatts. S. K. C. Transformers, Switchboard apparatus, etc., predominate to a like degree.

S. K. C. Apparatus is unequalled for Simplicity and Reliability.

Stanley Electric Mfg. Company, Pittsfield, Mass.

Fig. 307.

length. Under the lead of Prince Poniatowski, this company was merged into a larger corporation,

Standard Electric Power Company.

the Standard Electric Company, who formally announced their purpose of transmitting power to San Francisco, at a distance then estimated at 110 miles. This plant is designed to employ a pressure on the lines of 50,000 volts. In order to obviate the difficulties that exist in all districts where the rainfall is irregular, and characterized by heavy falls during one season of the year, followed by protracted droughts at other seasons, it has been decided to erect extensive reservoirs, with a storage capacity in excess of the most protracted periods of drought.

Dr. F. A. C. Perrine.

Dr. F. A. C. Perrine, from whom the preceding information has been obtained, thus describes the power plant of the Standard Electric Company:

Electra to Stockton and Mission San Jose.

"From the power-house at Electra, the lines lead through hill and dale through the city of Stockton on to the little town Mission San Jose, along the shores of San Francisco Bay, a distance of 100 miles from the power plant. At this point the lines diverge north and south, and are here controlled as a centre of distribution for the system. Thence they run north about 28 miles to Oakland and south to San Jose, around the Bay, and up to the north to San Francisco, making a total transmission distance of 154 miles—34 miles further than was originally contemplated, for the reason that originally it was intended to cross the hills direct to Oakland and cross the Bay district to San Francisco, but permission could not be obtained from the Government to erect poles and cross the 10-mile stretch of navigable water between Oakland and San Francisco, whereas the expense of submarine cables would have amounted to as much as the remaining expense of the entire line, the change in the distance and the lengthening of the line being made further justifiable

Why the transmission line was lengthened.

by the fact that all around the Bay are towns large and small, which form satisfactory customers for the power. The plant is now nearing completion, but, as I have already said, these men who have invested in the Standard Electric Company, have faith enough in the engineering that they are doing to be so sure of success, that they are unwilling to experiment with their customers, and only enter upon their period of regular operation after they have satisfied themselves with their plans and their construction work. In Oakland, San Jose, and San Francisco, they have added, as an additional safeguard against interruption of service, storage battery plants, and have installed, for charging these, motor-generator sets capable of being used in such a manner that, should accident occur along the line, both the alternating-current and direct-current service can be maintained by means of the batteries. This company is entitled to much of the credit for the exceedingly long-distance transmissions on the Pacific Coast, and while it may be unfortunate for their immediate glory that other plants are in operation before theirs is ready, their customers, in later years, will have reason to thank them for the care with which they have taken every step. Since their plans were laid out and the work begun, the Bay Counties Company found that they could make a contract with the Folsom Company, who supply Sacramento, and whose plant was deficient in capacity. Accordingly, they built to that city a line 60 miles in length, which they operate at 40,000 volts, supplying current in conjunction with the 10,000-volt plant 20 miles away at Folsom. The two plants, one at Colgate, 60 miles from Sacramento, operate in parallel with the Folsom plant, 20 miles from Sacramento. Later on, the Bay Counties Company built, and are now operating, a line 152

Precautionary measures of Standard Electric Company.

Sacramento supplied with electric power.

miles in length, from their plant to the city of Oakland. To reach this city they had to cross the navigable straits of Carquinez, through which the deep-water grain ships go from San Francisco Bay to the principal coast grain-shipping port of Porta Costa. Fortunately, these straits are bordered with high hills. At these hills they erected towers, and stretched their cables with a span exceeding 4,000 feet, effecting one of the most remarkable feats that have ever been attempted in long-distance power transmission. As the sub-stations and lines to this point belonging to the Standard Electric Company were ready for operation, this company have bought a large amount of power from the Bay Counties Power Company, which they transmit south to Mission San Jose, and thence to Stockton, San Jose, and up around the Bay as far as Redwood City, effecting a total transmission for the Bay Counties Company of 198 miles to San Jose, 200 miles to Redwood City, and 218 miles to Stockton. These distances are met successfully in every-day working, and the interruptions in supply have at no time been serious, nor has there at any time been any reason to feel that the work is at all of an experimental character. Up at Colgate their generators run day and night, supplying power to these distant points with the result that the company is successful not only from an engineering point of view, but financially successful with the success that has given confidence and strength to all electrical transmission securities along the Pacific Coast. These plants operate lights, mines, railroads, flour mills, and in every operation have given such service to their customers, that, in spite of the fact of recent discoveries of large quantities of fuel oil, their only difficulty is to find enough power to supply the demand made upon them."

A long-distance transmission plant in every-day use.

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